MISSOURI

GEOLOGICAL SURVEY

MISSOURI
GEOLOGICAL SURVEY

VOLUME VI.

LEAD AND ZINC DEPOSITS

(SECTION I)

By *ARTHUR WINSLOW*

WITH COMPLIMENTS OF

Charles R. Keyes,

STATE GEOLOGIST.

JEFFERSON CITY:
TRIBUNE PRINTING COMPANY, STATE PRINTERS AND BINDERS.
1894.

BOARD OF MANAGERS.

HIS EXCELLENCY, WM. J. STONE, GOVERNOR OF MISSOURI, JEFFERSON CITY,
ex officio President of the Board

DR. J. H. BRITTS.......................... ....CLINTON

HON. W. O. L. JEWETT..SHELBINA

PROF. E. M. SHEPARD, Acting President Drury College...............SPRINGFIELD

PROF. W. H. SEAMON, School of Mines..ROLLA

GEOLOGICAL CORPS.

CHARLES R. KEYES, STATE GEOLOGIST.

E. H. LONSDALE, ASS'T GEOLOGIST,
Building Materials.

C. F. MARBUT, ASS'T GEOLOGIST,
Topography.

H. A. WHEELER, ASS'T GEOLOGIST,
Clays.

ERASMUS HAWORTH, ASS'T GEOLOGIST,
Crystalline Rocks.

E. L. CARTER, SECRETARY.

LETTER OF TRANSMITTAL.

MISSOURI GEOLOGICAL SURVEY,
JEFFERSON CITY, JULY 1, 1894.

To the President, Gov. Wm. J. Stone, and the Members of the Board of Managers of the Bureau of Geology and Mines:

GENTLEMEN—I have the honor to transmit herewith the first section of the Report on the Lead and Zinc Deposits of Missouri, by Mr. Arthur Winslow, assisted by Mr. James D. Robertson, and to remain,

Your obedient servant,

CHARLES R. KEYES,
State Geologist.

PART I.

Lead and Zinc.

A general discussion of the history, compounds, modes of occurrence, distribution and industry of lead and zinc throughout the world.

PREFACE.

The examination of the lead and zinc deposits of the state, for the purpose of preparing a complete and comprehensive report, was started in the latter part of the year 1889, in co-operation with the United States Geological Survey, of which Major J. W. Powell was then director. Dr. W. P. Jenney was appointed from the National Survey to the charge of the work, and Mr. J. D. Robertson was detailed to assist him from the State survey by the writer, while State Geologist. Dr. Jenney pursued work in the State intermittently for over two years. During this period Mr. Robertson accompanied him, and acted immediately under his directions part of the time. In addition, however, Mr. Robertson, acting under instructions from the writer, extended his observations to localities not visited by Dr. Jenney, with the idea of gathering a complete series of mine descriptions to form part of the report. Not until the spring of 1892 was systematic study begun, in person, by the writer. Then, with the cessation of Dr. Jenney's work in this field, the scope of operations by the State survey was expanded so as to obtain material for an independent and exhaustive report. Since that time the study has been continuously pursued by the writer and Mr. Robertson.

The lead and zinc deposits of Missouri have proved of great and unexpected importance, outstripping all others in the Mississippi valley. Lead mining was begun as much as 170 years ago, and has continued uninterruptedly since. About the year 1854, however, the prediction was ventured by Prof. Whitney that the lead mining of Missouri was a thing of the past, and that the supply of ore was nearly exhausted. But, though individual bodies of ore have been exhausted, and though the industry has waned from time to time, deeper excavations have developed new bodies of untouched ores, wider explorations have revealed new fields, or improvements in mining or metallurgical processes have made previously rejected ores available. Along with this, the utilization of the associated zinc ores has led to the opening up of deposits which previously lay untouched, enclosing often unexpected quantities of lead. During the past twenty years Missouri's production has reached large proportions. The total amount mined during this period is fully twice that of the preceding 150 years—a striking refutation of the early adverse predictions. The output during recent years has been only second to Colorado's, and this year (1894) will probably be first among the states of the Union. The total production, from the beginning to the end of the year 1893, is represented by the handsome figure of 1,100,000 tons of lead ore, equivalent to about 750,000 tons of lead, valued at nearly $74,000,000. The output for the year 1894 will probably exceed 50,000 tons of ore, a large increase over 1893, despite adverse industrial conditions and depression of prices.

Similar in some respects are the facts of zinc production. The mining of these ores does not, however, date much more than twenty years back, and hence

the industry has not suffered much from the vicissitudes of the early mining. The production grew rapidly from its beginning, and now ranks first in the country. The total output up to the present time is nearly equal to the combined total productions to date of all other states in the Union, amounting to about 1,200,000 tons of zinc ore, equivalent to nearly 500,000 tons of metal, valued at about $50,000,000. The annual production is now considerably over 100,000 tons.

The productivity of individual ore deposits is, of course, very variable. There are undoubtedly many very small deposits of small yields, and there is much low grade ore. On the other hand, there are also many large deposits and much high grade ore, and some deposits have proved enormous and have yielded splendidly.

In illustration of the last statements, in the Southeast, Mine La Motte, which has been worked over 170 years, has produced lead to the value of about $10,000,000; the St. Joe mine, which has been worked for only 30 years, has produced lead to the value of nearly $14,000,000. The Valle mines, which have been operated about 70 years, have produced $2,000,000 worth of lead and over $800,000 worth of zinc ore, but this was from a number of different openings.

In the Southwestern district, the production of individual mines has not been so great, and the work is more scattered; yet, very large and rich deposits have been found. The following figures will illustrate the magnitude of the outputs by camps:

Production of Joplin camp for 1890 to 1892, inclusive	12,000 tons lead ore.
" " " " " "	67,000 " zinc ore.
" Webb City-Carterville 1890 to 1892, inclusive	12,000 " lead ore.
" " " " " " "	151,000 " zinc ore.
" Aurora 1886 to 1893, inclusive	26,000 " lead ore.
" " " " "	84,000 " zinc ore.

As instances of the yields of individual tracts, the Hatton lot of about one acre (200 feet square), on the land of the Center Creek company, of Webb City, produced over $300,000 worth of lead and zinc ore. Half of lots Nos. 1 and 2 of the Victor Mining company produced $275,000 worth of zinc ore. The Paxton land in Joplin, covering several lots, produced during the years 1877 to 1883 inclusive, $630,000 worth of ore, mainly lead.

These are, of course, among the largest yields, but there are many others that approximate them, and a large number of properties that have yielded at the rate of $100,000 per acre.

The methods of mining of the past have undoubtedly been crude, and they continue so to a great extent, especially in the southwest. In the southeast, larger and better planned operations are conducted, principally induced by the difference in the character of the deposits. It was among the plans of the writer to have instituted a study of the methods of mining, as well as of the milling and concentrating of the ores, which would have led to improvements and reductions of cost; but time and means did not permit this being carried out. In Jasper county, small tracts, 100 ft. or 200 ft. square, are usually worked on leases. Sometimes a number of such lots are combined under one lease; but frequently they are mined independently by separate individuals, often intermittently. Pumping is, however, quite

commonly done in co-operation. Royalties vary from 7½% to 35% of the value of the product. The customary royalty is about 10%, with pumping charges about 5% more. With leases of large tracts of many lots, aggregating ten to forty acres or more, the period is often as much as ten years, and the rate generally 7½% to 10%. The lands worked by the large mines of the southeast are generally owned by the operators; the smaller gash vein and channel deposits are let out on leases similar to those of the southwest.

The values of mining lands of course vary greatly. In the southwest, undeveloped properties on which there seems good prospect of finding ore. sell at from $50 to $100 per acre. Prospected lands, by drill or otherwise, which are not developed but show ore, bring from $100 to $200 per acre. Developed tracts showing promising bodies of ore, near producing mines, may command anywhere from $250 to $1000 per acre, and much more in exceptional cases. A six-year lease of 40 acres of land of the Victor mining property at Webb City cost $100,000, and, in addition, a royalty of 10% was paid the owner of the property. The Holden land near Belleville brought $1000 per acre. A 200-ft. square lot of the North Star property sold for $48,000, and 22½% royalty in addition. In the southeast, properties in the Flat River camp, which were prospected to a limited extent by drilling, sold for $200 per acre. Options on entirely unprospected lands in the immediate vicinity of large mines may be obtained all the way from $5 to $100 per acre. A tract of some 300 acres in the Flat River camp was recently purchased by the St. Joseph Lead company for $45,000, $1000 having been previously paid for an option before drilling.

A question may arise in the minds of some as to the objects of making this report so wide in scope as the table of contents shows it to be. In the opinion of the writer, the importance of Missouri in the lead and zinc world is ample justification. The object has been to make this a general work of reference on lead and zinc (of which none such has been written), with Missouri as a center. In this form the demand for and the circulation of the report will be much greater, with proportionate return to the State. In addition, the future of the Missouri industry is so dependent upon the conditions of other deposits throughout the world, upon circumstances of production and trade, that the outside information of the report is indispensable for the guidance of future developments. For similar reasons, and to make the report complete in itself, the incorporated extracts of previous publications relating directly to the deposits of the state have been introduced. In addition, the writer has endeavored to embody, and thus to place on record, all the notes of importance relating to the geology of the southern part of the state, which he accumulated during his occupancy of the position of State Geologist, and which the recent severance might prevent the publication of.

The acknowledgments due others for assistance during the progress of this work are many—far too many for individual mention of all to be included here. Effort has been made to give due credit in the body of the report. In addition, the writer desires to express special obligation to:

Mr. J. D. Robertson, for zealous and long-continued assistance during the progress of the work in all its stages, in the field, in the laboratory, and in the office. His work for nearly eight months since last spring has been almost entirely a labor of love.

Dr. E. O. Hovey of New York, for the contribution of his time and talents in the study of the cherts of the state, and in the preparation of the manuscript.

Mr. C. F. Marbut for his contributions to the geology of the southwest, and to Prof. E. M. Shepard likewise.

Miss Laura L. Mitchell for efficient and faithful services as stenographer and typewriter.

Major J. W. Powell, late director of the U. S. Geological Survey, and to the Hon. Chas. D. Walcott, the present director, to both for cordial support in many ways, and to the latter for his studies of the fauna of the Ozark stage, and for the results published in the report.

Prof. H. S. Williams of Yale University for his conclusions concerning the Eureka shale; to Dr. John M. Clarke of Albany, Prof. Chas. H. Beecher of Yale, Prof. E. O. Ulrich for observations on the Mine La Motte Lingulella.

Mr. Arthur Thacher of St. Louis for notes on the metallurgy of lead in the state, and for many suggestions and courtesies.

Mr. J. R. Holibaugh of Joplin for the many valuable statistics and maps of southwestern Missouri mines contributed.

Prof. Erasmus Haworth of Lawrence, Kansas, for gratuitous examination of specimens.

Dr. W. A. Metcalf of Steelville for guidance and assistance in the field, and for various contributions to the report; and to Col. A. W. Maupin of Union for like services.

Mr. W. C. Wetherill and to Judge O. H. Picher of Joplin, for assistance in obtaining statistics of productions and mine maps of that camp.

Mr. C. B. Parsons and to Mr. G. Setz of Bonne Terre; to Mr. F. W. Graves of Doe Run; and to Mr. J. D. Sanders and Mr. J. T. Monell of Mine La Motte, all for maps and notes relating to their respective mines, and for many courtesies.

Mr. J. H. Judson of St. Louis, and to Mr. H. Engleman, of Matthiessen and Hegeler Zinc Company, for many valuable figures of production and other notes and observations.

Mr. R. P. Rothwell, editor of the Engineering and Mining Journal of New York and author of the volumes of the Mineral Industry, for electrotypes of tables inserted, and for assistance in the prosecution of the work.

Gen. Geo. H. Nettleton, President of the K. C., Ft. S. & M. railway, and to Mr. Geo. C. Smith, while Asst. Gen. Man. of the Mo. P. railway, for assistance in many ways.

In conclusion, it is the earnest hope of the writer that this, the last of his reports for the Missouri Geological Survey, may prove of guidance to all, and of true service in the development of the mineral resources with which it deals.

CONTENTS.

PART II. LEAD AND ZINC IN MISSOURI.

A Report on the History of Mining in the State, on the Geology of the Mining Districts and of the Ore Deposits, and on the Lead and Zinc Industry.

PART III. MISSOURI LEAD AND ZINC MINES.

A Systematic and Detailed Description of the Important Developments and Occurrences of Lead and Zinc Ores.

LEAD AND ZINC DEPOSITS OF MISSOURI.

BY ARTHUR WINSLOW.

CHAPTER I.

HISTORICAL SKETCH OF LEAD AND ZINC.

ASIA AND AFRICA—EUROPE—AUSTRALIA—SOUTH AMERICA—NORTH AMERICA.

Lead and its properties have been known for a very long period, reaching back to before the beginning of history. Zinc was first recognized only a few hundred years ago, and is, hence, comparatively speaking, a modern metal.

In prehistoric times lead does not appear to have been extracted from its ores, either in Europe or in America. Thus, that metal is not found among the remains of the Swiss Lake dwellers, excepting in very small amounts in bronzes, where it may readily have been derived from the copper ores used. In America, specimens of galena have frequently been found in the mounds of the Mississippi valley; but no metallic lead. Whitney concluded [*235, p. 77*], after his examinations made before 1862, that the metal was, at least, not of common use among the Indians, and its reduction was probably taught by the white men.

Within historic times, however, the use of lead dates back to the earliest records in Asia, Africa, Europe and America. In the next following pages we shall briefly sketch the progress of mining and the use of these ores in the different countries, during past centuries. The conditions at present and during recent years will be found in the chapter on the lead and zinc industry, while details of history will be found in the description of deposits.

ASIA AND AFRICA.

Asia and Africa are so intimately connected in Biblical and other early history that they are best considered together.

Lead.—Pliny attributes the discovery of lead to Midas, King of Phrygia, in Asia Minor, a somewhat legendary personage who reigned over a thousand years B. C. Lenormant,* however, declares that the Chinese were acquainted with all metals as early as 2000 B. C. Lead and iron mines were exploited in the desert near the Red sea in the time of the ancient Egyptians, and the metal, as well as litharge, was known to these people. Solder containing the former is found in ruins ascribed to the time of the Pharaohs. The Israelites were commanded by Moses (about 1500 B. C.) to purify lead (called *opheret)* by fire; but they made no exact distinction between this metal and tin.

In Assyria, Phœnicia, Arabia, Armenia, Chaldea, Persia, India and China are deposits of silver lead ores which were worked by the ancients; and in Tunis and Algeria also. The Phœnicians (1550–55 B. C.) also worked lead mines in Cyprus and Thasos. The separation of silver from lead, by simple melting and oxidation, was prosecuted before 600 B. C. in the East. In Japan, lead mining was prosecuted as early as the 8th century.

The uses to which lead and its compounds were put by the ancients were numerous asd often peculiar. The Chinese are credited with having used flattened lead as money probably as early as 2000 B. C., and it was also used there for debasing more valuable coinage. In India it was used as weaver's weights and also as a charm; red lead was used as a cosmetic, and the medicinal applications of this and other compounds were various. The Egyptians glazed pottery and made solder for wares from lead; they also made amulets and other objects. Wooden anchors of the Phœnicians were filled with lead. They also used leaden coffins. Lead was used in glass as early as 800 B. C. The masonry of ancient Babylon was strengthened by iron clamps held in sockets by lead, and the hanging gardens were floored with sheet lead. Lead was generally added to ancient bronzes. Lead pipes were also used in Asia and Arabia. White lead was used as an ointment by the Egyptians, but not as a pigment.

Zinc.—The only clue which we have to the uses of zinc in these countries in ancient times is in the references to brass and bronzes, the two being probably often confounded. The properties or even the existence of the metal itself were not known. Bronzes are known to

*L'Orfeverie d'Etain. Revue Archeologique; quoted by Pulsifer in his Notes for a History of Lead. To this painstaking and exhaustive work of Mr. Pulsifer the writer wishes to make acknowledgments for many of the facts of the following historical sketch.

have been made by the Egyptians. Moses refers to brass in Numbers (XXXI, 22), and mention is made of it elsewhere in the sacred writings. The manufacture of bronzes and brasses, says Robert Hunt [*116, p. 5*], appears to have been engaged in from a very early period by some branches of the Phœnician people and the Assyrians. Coming down to comparatively recent times, the discovery and production of the metal zinc is to be accredited to the East; for, before even its ores were recognized in Europe, Libavius (1597), who first investigated the properties of the metal, speaks of it as a peculiar kind of tin found in the East Indies, whence some brought to Holland came into his hands [*194, vol. ii, pt. i, p. 251*].

LEAD IN EUROPE.

Lead mining of Europe probably began along the shores of the Mediterranean, where the knowledge of the metal was most readily acquired from the East.

The Laurium mines, in Greece, are thought to have been worked as early as the Trojan wars (about 1200 B. C.), and articles of lead were found by Schliemann among the ruins of ancient Troy. The Phœnicians established themselves at Cadiz as early as the 12th century B. C. and engaged in or stimulated the mining of lead and other ores of southern Spain, and probably those of France also. The Sardinian mines were also worked by them, and probably those of northern Spain and Sicily. The Carthaginians, succeeding the Phœnicians, continued with and encouraged mining in these countries.

Greece.—In Greece, lead mining was conducted on a large scale at Laurium during the 6th and 5th centuries B. C., and to a more limited extent down to the Christian era. After that it was practically abandoned until 1864. The metal was put to many uses here during the early centuries. Bronze coins, between the years 500 B. C. to 50 B. C., contain from 3 to 30 per cent of lead. Bullets for slings were made of it. It was also made into pipes. Other objects were images and ornaments, weights and scales. White lead (composed probably of a mixture of the acetate and carbonate) was used as an ointment or cosmetic. At the beginning of our era this was manufactured in large quantities in Rhodes, and also at Corinth and in Lacedemonia.

Brass was also manufactured. It is referred to by Aristotle (400 B. C.) as Mossinœcian copper, made by melting copper with a peculiar earth from the shores of the Black sea. A Greek coin of Trajan, struck in Caria 110 A. D., contained 20.7 per cent of zinc.

Romans and Italy.—The Romans, succeeding the Carthaginians, conducted lead mining on a large scale in Spain, Sardinia and near Africa, and they extended operations into France and England, and perhaps into Austria. They utilized the metal for the same purposes as the Greeks, and also in masonry, in hoops for casks, lids, armor, buckets, and even for kettles, despite the fact that its poisonous properties were known. Water-pipes of this metal were employed extensively, some as much as 30 ins. in diameter. Coffins and vases were also made of it.

After the Roman period, mining languished for centuries both in Italy and other countries. In the 11th century the Sardinian mines were reopened; they were worked again about 1720, and during the past 40 years they have been continuously operated, as will appear in the descriptions later. The mines of Sicily were reopened in 1747, but later were abandoned. Mines of the Italian Alps and Piedmont were worked in the Middle Ages.

France.—In France the Phœnicians and Gauls are supposed to have worked silver lead ores before the Romans. After the operations of the latter, mining was largely abandoned from the 4th century to the time of Charlemagne (800), when a stimulus was given to the industry. It sank again after that, however, and Spain was principally depended upon as a source of supply. The Moors operated mines in the Pyrenees. A revival prevailed during the 11th and 12th centuries, to decline again in the 13th. Lodes of the Vosges were discovered in 1313. Operations were resuscitated in the 16th century and continued through the 17th and 18th, though on a more limited scale.

At Pontgibaud records date back only to the 16th century, but remains of early workings indicate a very early date of mining here. Ever since the 11th century operations have been conducted at intervals. At Huelgoat work was done before 1578. At Poullaouen opertions commenced in 1729, and over 1000 men were employed in 1760. The mines of the Vosges were worked in 1581 and in the last half of the 18th century. During the latter period mining was in progress in a number of other districts, and also in the Alps.

The metal was used in France for the ordinary purposes already enumerated, and, during the Middle Ages, it was employed in coins, in vessels and utensils, and for small sacred images.

Spain.—The remarkable lead deposits of Spain were well known to the ancients, having been worked by the Phœnicians, Carthaginians

and Romans. Spain then ranked among the foremost mining countries. Under the Moors mining also flourished, but declined after their expulsion and the discovery of America in 1492. Active work on the Linares deposits began, however, during the last half of the 16th century, and has continued ever since. From the beginning of the 16th century to 1825, comparatively but small quantities of ore were produced. In that year, however, the mining lands were practically thrown open to exploitation of all, by royal decree. The production of lead ore then grew immediately to great volume. The mines of the Sierra Gador and Sierra Lujar were particularly productive, these yielding in 1827 nearly 47,000 tons of lead. In 1839 the deposits of Sierra Almagrera were discovered. Deposits in Portugal were also worked from very early dates.

Germany.—Of lead mining by the early German tribes, the Saxons, the Goths and others, we have found no mention. Iron ores were mined and reduced by them, and it is probable that the comparatively simple processes of lead smelting were known also. About the earliest recorded mining in Germany was in the Harz mountains, near the middle of the 10th century. Work was prosecuted here only in a desultory manner, however, until the 15th. Mining at Freiberg, in Saxony, was begun during the 12th century. In Silesia the industry was flourishing in the 13th century, and at that time Germany was one of the principal centers. Mining appears to have declined after this; but in the 15th and 16th centuries the works were reopened, and have been exploited vigorously ever since.

Belgium.—Mining in Belgium is of remote antiquity. Ancient documents indicate that operations were conducted at Vieille Montagne over one thousand years ago, for securing calamine, and doubtless the associated lead ores also. Work is also reported to have been done here by the Spaniards 450 years ago. Records do not date back beyond 1640, however.

Bleiberg, the principal lead deposit, was mainly operated during the last fifty years. The lead ores of Belgium are now practically exhausted.

Austria.—In southern Austria the Carinthian deposits were probably worked during the Roman period, and they were certainly actively developed during the Middle Ages.

Near Przibram, in Hungary, mining was begun about the middle of the 9th century, and at Mies before the year 1100. At Schemnitz

developments date from the 12th century. During these early years, however, operations were not extensive, and were prosecuted in a desultory way. Early in the 16th century the Przibram mines were reopened and have been worked extensively since.

The Schneeberg mine in the Tyrol was worked on a large scale for lead in the latter part of the 15th century.

Russia.—Among the earliest traces of mining in Russia are those found in Siberia, where sledges made of stone and of the teeth of animals are assigned to the 2d century B. C. The lead mines in the province of Irkoutsk were discovered in 1691. In the Caucasus silver lead mining also dates from remote antiquity. In Poland large amounts of lead were produced during the 16th and 17th centuries.

In Sweden the great lead deposits of Sala are reported to have been worked as early as the sixth century and were certainly worked by 1280.

Great Britain.—There is no positive evidence of lead mining in Great Britain by the ancient Britons, but there are reasons for believing that deposits of Cardiganshire and of some other counties were worked by them.

From the beginning of the Roman occupation (55 B. C.), however, there is indubitable evidence of great activity, in the shape of old waste and slag heaps, old furnace remains, coins, tools, pigs of lead with Roman brands, etc. Such are found in North Wales, in Northumberland, Durham, Cumberland, Yorkshire, Flintshire and Somersetshire. In the Isle of Man are also traces of very early work.

After the Roman period, mining languished, but was continued, though on a reduced scale, by the Saxons and Danes. Before the Norman conquest several Derbyshire mines were worked, and these were about the only ones that continued in operation up to 1289.

In Shropshire the old Roman Gravel mine was worked during the 12th and 13th centuries. In Devonshire large silver mines of Beer Alston were in operation in the 13th and in the 15th centuries.

The first records of operations in Cardiganshire are in 1485; the mines here were also extensively operated during the reign of Queen Elizabeth.

The North of England lead mines were not worked after the departure of the Romans until 1468, since which time they have been in operation at frequent intervals.

Generally speaking, the 16th, 17th and 18th centuries constituted a period of great activity in lead mining in England; large amounts were produced and large quantities were exported.

ZINC IN EUROPE.

We have already noted that zinc ore was used before the Christian era in the manufacture of brass and bronzes, and it was found in coins. Its use in this way continued for many centuries without the metal being discovered. Copper ores containing zinc were the first used, the brass being made directly. Later, after the discovery of zinc ore, the copper was produced first and the zinc ore was added to convert it into brass.

The ore was generally the carbonate, known commercially in Europe, together with the silicate, as calamine. It was called *cadmia*[1].

Calamine was obtained before the Christian era from the island of Cyprus. In Belgium ancient documents relate that calamine was raised near Moresnet at the beginning of the 7th century, but they are of doubtful authenticity. There are reasons for believing that the development for calamine of the Vieille Montagne deposits began about the 12th century with the manufacture of brass. In 1435 the grant of concessions is recorded [*209*, p. *95*].

In Great Britain the earliest traces of brass are in the mediæval monuments. Here, as elsewhere in Europe, a prominent use was in memorial tablets, known as sepulchral brasses. It was highly valued for many purposes, and under Henry VIII, an act was passed prohibiting the export of brass, which was not withdrawn for nearly 300 years. Under Queen Elizabeth a patent was granted for using calamine in the manufacture of brass. In 1721 thirty thousand persons were employed in brass founding in England. Profitable brass works were conducted in the Harz during the 16th century, but not until the end of the 16th century was the idea advanced by Kunkel that brass was an alloy.

White vitriol, or sulphate of zinc, was first manufactured in 1570. It was used for dressing leather and for medicinal purposes.

The discovery and first mention of the metal zinc was by a Dominican monk, Albertus Magnus, in the 13th century. He also first described the use of furnace calamine in making brass. Probably in

[1] The word *cadmia*, according to Beckman [*11-vol. ii, p. 33*], signified any mineral abounding in zinc, as well as any ore including the natural calamine. The furnace-calamine was also given this name.

this furnace product at Goslar he found the metal. He called it *marchasita aurea*. Paracelsus, who died in 1541, first described it definitely. His description, as given by Beckmann, is as follows: [*11, vol. ii, p. 41.*]

There is another metal, zinc, which is in general unknown. It is a distinct metal of a different origin, though adulterated with many other metals. It can be melted, for it consists of three fluid principles, but it is not malleable. In its color it is unlike all others, and does not grow in the same manner; but with its *ultima materia* I am as yet unacquainted, for it is almost as strange in its properties as *argentum vivum*. It admits of no mixture, will not bear the *fabricationes* of other metals, but keeps itself entirely to itself.

As late as 1617 the metal remained an accidental product of the Goslar furnaces, much sought after by alchemists. Its exact nature continued more or less doubtful throughout the 17th century; it was often confounded with bismuth.

Up to the 18th century all that was used commercially was imported from the East, where it was distilled by a special process called *per descensum*. Large quantities continued to come from there as late as 1750. The exact source is not known, but the principal contributing countries were apparently China, Bengal, Malacca and the Malabar coast. The eastern metal was probably introduced into Europe before the beginning of the 17th century, and was doubtless discovered in India before the European metal was known. It was Indian zinc that Labavius investigated the properties of in 1597.

The first in Europe who intentionally procured the metal from calamine was Kunkel, probably about 1720. He gave a partial account of the process in 1741, after learning of its production in England. Dr. Isaac Lawson of England apparently made a similar discovery shortly after [*116, p. 132*].

In 1742 Von Swab experimented in Dalecarlia on the production of zinc by the distillation of roasted blende and coal. It proved too costly, however. In 1746 Margraaf made further attempts. Cronstedt and Rinmann finally perfected the process known as *per ascensum*, or the Silesian method[*197, p. 2*].

The beginning of the industry in England followed the visit of an Englishman (probably Dr. Lawson) to China to discover the process there. As a result, works were established at Bristol in 1743.

The first continental zinc works appear to have been established in Silesia abourt 1798. Early in the present century the Abbe Dony began to experiment in the methods of reduction, which resulted in the Belgium process. He applied for a patent in 1809, and established

the first zinc works of Belgium at Liege. These were later developed by Dominique Mosselman, and have since grown to their present dimensions. Not until about 1820 did the manufacture of zinc in Europe begin to be a well-established industry.

OCEANICA.

Lead mining in Australia, of which we have any record, does not go back over 40 years. No zinc ore is mined or known to occur there in quantity.

SOUTH AMERICA.

The silver mines of Peru were worked probably at an early date. Certain it is that before the conquest, in 1533, they were sources of precious metals to the native Peruvians. They also knew lead—articles of this metal having been found in the ancient graves. The mines were worked by the Portugese, and assumed large dimensions after 1630. In Bolivia the silver mines were discovered in 1545, and were worked on a large scale from then into the 17th century. Mining in Chili is of later date, probably beginning in the 18th century.

NORTH AMERICA.

Mexico.—The oldest mining in North America was in Mexico. The Aztecs, before the conquest, worked the silver and lead deposits along with others. Lead was obtained from mines near Tasco. The Spaniards opened mines from 1520 on, but the most active period was after 1700. Work was begun on the Zacatecas deposits in 1548. They were important producers of silver and lead. The Guanajuato deposits were opened in 1559. The massive deposits of Sonora and Chihuahua are of quite recent discovery.

After the expulsion of the Spaniards in 1821, foreigners were allowed to enter, since which time English and later American capital have done much to develop the mines.

In Honduras mining was in progress over 200 years ago.

In Canada the discovery of lead ores is of very recent years, and nothing of historic interest is to be recorded. Of zinc there is nothing to be said.

THE UNITED STATES.

Lead Mining.—The earliest discoveries of the United States appear to have been in Virginia, near Jamestown. Here, John Berkeley, who was in charge of a pioneer iron furnace, discovered a small

vein of galena which he worked for bullets and shot. The same deposit was subsequently worked by a Col. Boyd. The Wythe county deposits of the eastern part of the state were not discovered until 1750, by a Col. Chiswell, a British officer. Development was begun at once, and with interruptions during various periods, has continued till the present time.

The Washington mine in North Carolina was discovered in 1836, and has been worked continuously since, to recent times.

In Maryland some little lead mining was prosecuted near Unionville, prior to the revolution. In other southern states little was done.

In Pennsylvania the existence of metalliferous deposits was known at the time of the Swedish settlement [*177, p. 75*] in 1640, and probably included the Chester county lead ores. Lead mining in Huntington county was of early date, and was possibly prosecuted by the French. The Blair county deposits were discovered and worked during the revolution, in 1778, and again in 1795. The principal operations, however, were between the years 1864 and 1870, Those of Lancaster county were first known in 1845, but extensive work was not begun until 1873; those of Northumberland were discovered about 1850, though not worked until 1882. Recorded mining of the Chester county ores began in 1850.

In New York Governor Crosby announced a discovery of lead ore in 1734. A vein of argentiferous galena was worked at Ancram, in Columbia county, before 1740, and quite extensively afterward. A band of German miners opened a vein about the same time in Dutchess county. In Ulster county the Ellenville mine was opened in 1820, and was worked during a number of years afterward, as well as other deposits in the same county. The Rossie mine of St. Lawrence county dates from 1825, and was worked during the immediately succeeding years, and again about 1852. In Sullivan county, the Shawangunk or Montgomery zinc mines started in 1837, but, after a few years of operation, were abandoned until 1852. During the past 40 years little lead mining has been done in the state.

The Connecticut lead deposits, near Middletown, were apparently known early in the 17th century, and were probably worked by John Winthrop about 1650. [*177, p. 75.*] They had certainly been mined before the Revolution.

In Massachusetts, the existence of lead ore was reported as early as 1632 [*15–vol. i, p. 493*], but the first notice of mining was in 1765,

at Southampton, about 10 years after the discovery of the deposits there. At Worcester, ore was dug about the same time. Operations at Southampton were resumed in 1809, and continued 20 years by one miner; in 1850 a little additional work was done. The Northampton vein was worked a little during 1854. The Newburyport deposit was not discovered till 1874.

The New Hampshire deposits at Eaton were discovered in 1826, and were worked at intervals duringthe next 30 years. The Shelburne mines were operated between the years 1846 and 1849.

In Maine, the Lubec mines were opened in 1832, and small quantities of ore were produced. These and other New England deposits have dropped out of notice during the past 50 years, with the development of the richer and much more extensive ore bodies of the Mississippi valley and of the western country. Their principal interest lies in their isolation and historic associations.

In the Mississippi valley, the earliest report of the discovery of lead ore is that of Nicolos Perrot [*121, p. 498*] in 1692 in Wisconsin, but this is of doubtful reliability. Certain it is, however, that Lesueur found the metal in both the upper and lower Mississippi areas in his expedition of 1701.

The development of the extensive Missouri deposits much preceded that of Iowa and Wisconsin. It began about 1720, at Mine La Motte and other localities. It continued from then uninterruptedly to the present time, increasing almost constantly in magnitude, though there were a few periods of partial interruption. The western Missouri ore bodies were hardly known before 1850, and they were not extensively opened until about 1870; since then their yield has increased enormously.

In the upper Mississippi area, nothing seems to have been done until nearly the last decade of the 18th century. In 1766, John Carver found lead at Blue Mound. About 1788, Julian Dubuque began mining at Dubuque, and continued until about 1810. After this, little was done until the occupation of the country by Americans in 1821. Then the developments of lead mining over the whole upper Mississippi area became rapid, and the industry assumed large dimensions between the years 1840 and 1850. Since that time it has been comparatively small.

In southern Illinois the Massac and Hardin county deposits were opened before 1821. The Rosiclare mine was discovered in 1839 and

worked about 1842. Operations in the adjoining counties of Kentucky were principally between the years 1865 and 1875.

In Kansas, Swallow [*218, p. 58*] refers in 1866 to a little lead ore found in Miami and Linn counties. Attempts had been made to mine it before then. The only important deposits, in Cherokee county, were not discovered until 1876.

In Arkansas, lead and zinc ores have been known for fifty years. Only desultory mining has been done.

The great lead ore bodies of the far west are of comparatively recent development, none being generally known forty years ago.

In Utah the Mormons claim to have mined the silver lead ores of Beaver county in 1861; those of Bingham canon were opened in 1863. The deposits of the Cottonwood district, including the Emma, were discovered in 1864; the Emma mine was not opened until 1870, however, and was abandoned in 1875. The Horn Silver deposit was discovered in the latter year.

In Nevada, the Lander county deposits were discovered as early as 1862; the Eureka deposits soon after, in 1864, but their value was not determined until 1870. Those of Lincoln county were also discovered in 1864, of Esmeralda county in 1867, and of the White river district in 1869.

In Montana, the argentiferous galena of Jefferson county was known before 1865, and smelters were soon after erected. Because of difficulties of transportation, however, much ore was not smelted for some ten years.

The Colorado lead and silver deposits at Georgetown were worked in 1866, but the great carbonate deposits at Leadville were not discovered until 1874, and mining was not well under way there until 1876. The Aspen deposits were developed about 1882.

In Idaho, argentiferous galena was discovered near Idaho City as early as 1867, the South Mountain deposits about 1871, the Wood River in 1873 and the Cœur d'Alene within the past ten years.

In South Dakota, most of the little lead mining done has been during the last decade.

Zinc mining.—The association of zinc ores with the lead ores of many of the deposits of the United States, both in the east and the west, led necessarily to this mining along with the latter ores. To the majority of miners zinc compounds were probably unknown and hence not recognized. It is probable, however, that their existence in

the country was known before the beginning of the present century. The earliest reference to such ore in the Mississippi valley is in 1810; the New Jersey franklinite deposits were discovered in 1820 by Dr. Fowler [*28, p. 146*].

Zinc was first manufactured in the United States in 1838 [*178*]. This was at the arsenal in Washington. The ore used was the red oxide from New Jersey. The process proved very expensive, and nothing further was done.

The New Jersey Zinc company was organized in 1848 with works at Newark. Numerous attempts had been made to utilize the Sterling Hill ores, but none were successful before this. The Belgian method was first adopted, but was not a success, because of the corrosive action of the oxide of iron in the ores upon the retorts. This failing, the manufacture of zinc-white was perfected and continued uninterruptedly.

The Saucon Valley deposits in Pennsylvania were discovered in 1845. In 1853 the who e property was acquired possession of by the Pennsylvania and Lehigh Zinc company, and zinc-white furnaces were erected at Bethlehem under the direction of Samuel Wetherell. In 1856 experiments were conducted at these works by Matthiessen & Hegeler for the reduction of the ores by the Silesian method, but this failed also. Wetherell then experimented with open furnaces, drawing the vapors through beds of incandescent anthracite; Joseph Wharton tried a similar process at Camden, New Jersey, but both undertakings failed. Wetherell finally returned to the use of the upright retorts, and was able to prepare them of sufficiently refractory materials. The Lehigh Zinc company then returned to the Belgian furnace, and the Bethlehem works were erected in 1860. After that date works were built at Newark, New Jersey, Bergen Point and Trenton.

Small zinc works have been erected at Constable Point, in New York, and near Ansonia, in Connecticut [*12, p 15*].

The Blair county (Pennsylvania) zinc deposits were operated between 1864 to 1870, and those of Lancaster and Northumberland counties later. Works were erected in Lancaster county and at Birmingham in that state.

The Wythe county zinc ores of Virginia were not utilized until after the war. Furnaces have been built here and also at Knoxville, in Tennessee, during recent years, for the reduction of the home ores.

In the Mississippi valley the beginning of the zinc industry was with the erection of the works at Mineral Point and at La Salle, Illinois, by the Matthiessen & Hegeler Zinc company in 1860. Those at Peru were built later.

In Missouri zinc was not manufactured until 1867, when a small plant was erected at Potosi. The Martindale zinc works at Carondelet were established in 1869. Following closely upon these were established at the same place successively the works of the Missouri Zinc company and of the Carondelet Zinc company; at St. Louis, those of Page and Krause and Washington furnace; and in Washington county the Hopewell furnace. The great zinc deposits of Newton and Jasper counties were not drawn upon until 1871. These ores were first shipped to LaSalle, but, in 1873, the Weir City (Kansas) works were built, and others at Pittsburg in 1873. The Joplin and other Missouri works were not built until after 1883.

CHAPTER II.

LEAD AND ZINC AND THEIR COMPOUNDS.

THE METALS—NATURAL COMPOUNDS OF LEAD—NATURAL COMPOUNDS OF ZINC.

THE METALS.

Lead.—Lead is a bluish-gray, opaque metal, very soft and malleable, but only somewhat ductile. It is readily cut with a knife or scratched with the finger-nail, but is not easily drawn into very fine wire. It crystallizes in the isometric system in octahedral or dodecahedral forms [*57, p. 24*], but is rarely found crystallized and usually occurs in thin plates and small globules, or in dendritic, wire-like forms.

The hardness of lead is 1.5 its specific gravity, according to Dana, 11.37, and according to Deville, 11.363 [*251, p. 360*], while Reich determined it for ingot lead to be 11.352, and for sheet lead 11.354. Its fusibility is about 330° C. (334° Person); it emits vapors at a red heat and volatilizes at a white heat. Fizeau determined the expansion of a unit of length from 0° to 100° C. to be .002948, and its electric conductivity, according to Weidemann and Franz, is 8.5, that of silver being 1. Its specific heat is .0314 (Regnault). Its tensile strength is very low, a wire $\frac{1}{10}$ of an inch in diameter being broken by 30 lbs. Broken by torsion at ordinary temperatures it exhibits a fiberous fracture; broken by the blow of a hammer at a temperature near fusion, it shows a somewhat crystalline fracture. It tarnishes readily on exposure to the air or on contact with water and air.

Pure water has no action on lead at ordinary temperatures, though the presence of a small amount of antimony (1.7 per cent) in the metal renders it slightly soluble, according to Bischof. Vapor of water is decomposed by lead at a red heat. It is readily soluble in dilute, cold nitric acid and in concentrated boiling hydrochloric acid; it is not attacked by dilute sulphuric acid, but is dissolved by the boiling con-

centrated acid, though in this case Hasenclever and others determined that the small percentages of antimony retarded solution. In the absence of air, acids in general do not attack lead at ordinary temperatures [*162, p. 6*].

The metal may be said to be never absolutely pure, and contains generally small quantities of silver or antimony, copper and iron, with occasionally zinc, nickel and bismuth. These impurities are associated with various brands of commercial leads, and affect their uses in the arts; the presence of about 2% of arsenic hardens the lead and is hence added in shot; antimony, zinc, bismuth, arsenic and silver increase its brittleness. Lead and its compounds are poisonous.

Various alloys of lead are used, the principal of which are: type metal, consisting of 80% lead and 20% antimony; hard and soft pewter, composed of tin with respectively 8 and 18% of lead; and plumbers' solder, consisting of 66% of tin and 33% of lead. Such alloys fuse generally at a lower temperature than either of the metals alone. Thus an alloy of lead, bismuth and tin, in the proportion of 5-8-3, fuses at 94.4° C, while one, known as Woods alloy, composed of these metals in the proportions of 8-15-4 and 3 of cadmium, fuses at 70° C. Molten lead and zinc do not mix in all proportions; lead takes only 1.6% of zinc, while zinc takes only 1.2% of lead. An addition of 1% of zinc to lead makes the lead harder and susceptible of polish, though not less malleable. An addition of bismuth makes the mixture more homogeneous. Lead alloys with silver in all proportions, the alloy being more fusible than pure lead; also with arsenic, tin, antimony, bismuth, mercury, thallium and manganese.

Zinc.—Zinc is a white, lustrous, opaque metal, susceptible of a somewhat high polish. In familiar forms it is not malleable or ductile, but somewhat brittle at ordinary temperatures. The texture is always crystalline, sometimes granular, sometimes lamellar.

Pure zinc is ductile and malleable; much less so if impure, like the zinc of commerce, which can be broken with the blow of a hammer. It is made more ductile by regular compression [*197, p. 13*]. Tin and copper diminish the malleability; iron increases the hardness if not in excess; cadmium makes a malleable alloy. Wurtz observes that zinc becomes malleable at a few degrees above 0°, but when heated to 200° C. it again becomes brittle, while between 100° and 150° it may be drawn into wire and rolled into plates. When cast at a temperature

near the melting point it is more malleable than when cast at a higher temperature, and is also less acted upon by acids [*165*].

Zinc fuses at 410° C. (Wurtz), 433° (Person), and volatilizes at 891 (Becguerel), 1040° (Deville and Troost). Its hardness is 2, being thus somewhat softer than copper and harder than lead. Specific gravity according to Bolley, varies from 7.109 to 7.178; according to Brisson and Karsten from 6.861 to 7.300 with different physical conditions. Specific heat is .09555 between 0° to 100° C. [*165*.] When heated from 0° to 100° C. zinc increases $\frac{1}{340}$ in length. Its heat conductivity seems to be very variable, or at least the results are very discordant, varying from 19 (Wiedeman) to 64.1 (Calvert and Johnson), that of silver being taken at 100. The electrical resistance of a wire 1 mm. in diameter, per meter of length, is .0724 ohms; it increases with temperature.

According to Berthier, a zinc wire .0784 inches in diameter breaks under a weight of 26.455 lbs. [*165*]. With Werthiem, a permanent elongation of $\frac{1}{2}$ mm. per meter, of a bar 1 mm. square, took place with tensions of .75, 1.00 and 3.20 kilograms, according as to whether the bar was drawn, annealed or cast [*197, p. 15*]. The same observer determined that the coefficient of rupture of a wire 1 mm. in diameter was 1.5 kg., with cast metal, and 12.50 with the drawn and annealed.

Zinc crystallizes in rhombohedral forms of the hexagonal system. Dana notes that it also appears to crystallize in the isometric system, at least in various alloys.

It tarnishes on exposure to air, but an oxide,* or a hydro-carbonate of zinc is then formed, which protects the metal from further oxidation. This fact makes the metal valuable for out-door uses; thus, Pettenkofer found that a sheet of zinc exposed as part of a roof for 27 years was oxidized to a depth of only .01 mm.

The fracture of zinc is granular or coarsely crystalline, dependent upon the temperature of casting.

Zinc dissolves in hydrochloric and sulphuric acids and in boiling solutions of potassium and sodium hydrates. The pure metal does not dissolve readily in acids, and the easy solubility of commercial zinc is attributed to the galvanic action produced by the presence of small quantities of other metals. Heat and concentration generally increase the solubility. Nitric acid dissolves it freely. Sea-water attacks the metal much more than pure water.

*Berzelius regarded this as a definite sub-oxide, but Proust, Davy and most chemists have regarded it as a mixture of oxide and finely divided metal.

Zinc precipitates a large number of other metals from a solution of their salts; it reduces many oxides, sulphides, chlorides, bromides, iodides and fluorides.

There are a number of alloys of zinc, the most common being brass, which consists of copper mixed with from 10 to 35% of zinc. German silver is an alloy of copper, zinc and nickel. Some bronzes also contain small quantities of zinc. It also alloys with antimony, platinum, tin, iron, mercury, silver, potassium, sodium and aluminum.

Commercial zinc always contains small quantities of lead, iron and carbon. Not infrequently small traces of sulphur, arsenic, antimony, tin, copper, manganese, nickel and cobalt are present. About the purest zinc manufactured is from the red oxide of New Jersey. American zinc does not contain appreciable quantities of arsenic. Cadmium particularly characterizes Silesian zinc; tin specially that of Swansea and New Jersey [*197, p. 6*].

THE NATURAL COMPOUNDS OF LEAD.

Both lead and zinc are very rarely found in the native state; but they are essential constituents of a great number of mineral species. Comparatively few of these species are, however, of common occurrence, and a still smaller number occur in sufficient quantities to be of commercial importance and to appear in ores as technically defined. This fact will be allowed to control the following descriptions of compounds; chief prominence and attention being given to those minerals which constitute ores, while those of rarer occurrence will be only briefly referred to.

By far the most common lead compound is the sulphide-galenite, familiarly called galena; after this come the carbonate, cerussite, the sulphate, anglesite, and the phosphate, pyromorphite; the oxide minium is also abundant in some localities. Of zinc, the sulphide, sphalerite, more generally known as blende, is also the most common of ores, though the hydrous silicate, calamine, and the carbonate, smithsonite, are almost equally so; the hydrous carbonate, hydro-zincite, the oxide zincite, and the anhydrous silicate, willemite, are also of frequent occurrence.

Native Lead.—Very rare; generally in thin plates or scales; found in dolomitic limestone at iron and maganese mines in Wermland, Sweden. At the Harstig mines isometric crystals occur, with a small per cent of silver (less than 0.3%). Hartman regards the metal to have

been reduced by arsenious acid. It has been recognized in meteorites. [*162, p. 2.*] It is also found in gold washings of the Urals; doubtfully in globules in galena of Alston Moor, England; in lava of Madeira; in Carthagena, Spain; in carboniferous limestone near Bristol and at Kenmare, Ireland; in amygdaloid near Weissig; in basaltic tuba in Moravia; in Vera Cruz in limestone, and in Peru. Recently its occurrence near Saric, Sonora, Mexico, has been noted in thin scales and small pellets. In the United States it is found in limestone near Saratoga (?); at Breckenridge and Gunnison, Colorado; in the Wood river district, Idaho; and in the gold placers of Montana. According to Bischof, when found in cavities of volcanic rocks it may have been reduced by high temperatures.

Galenite *

Syn.: Galena, lead sulphide, sulphuret of lead, lead glance, potter's lead ore, specular galena, "mineral," slickensides, gravel mineral.

Var : Johnsontite or supersulphuretted lead (with excess of sulphur by decomposition), bleischweif (with Zn, Fe, Sb), targionite (with Sb, Fe), steinmannite (with As, Sb), fournetite (with copper ore), plumbeine (pseudorph after pyromorphite).

This mineral is of pure lead gray color, opaque, and with a bright metallic luster. Specific gravity 7.4 to 7.6; hardness 2.5 to 2.75. It melts at a red heat, and is volatilized at a higher temperature.

It crystalizes in the isometric system, commonly in the form of the cube or cubo-octahedron, less often octahedral. It has a highly perfect cubic cleavage and a less perfect octahedral one.

It is composed of sulphur and lead (Pb S), containing 86.6 parts of lead and 13.4 parts of sulphur. As accessory constituents there is always some silver present and occasionally sulphides of zinc, copper, cadmium, antimony, bismuth, and sometimes native silver and gold.

It is decomposed by strong nitric acid, the sulphate of lead being formed, and by concentrated boiling hydrochloric acid forming chloride of lead. It is practically insoluble in water, but is soluble in waters containing alkaline sulphides.

Galenite is generally found in imperfectly formed cubes—these frequently in clusters, with octahedral faces developed on some of the corners, and with other portions of irregular outlines attached to rocks or other minerals; it also occurs in lenses and in massive sheets, and

(*) For much of these descriptions of mineral species we are especially indebted to Dana's System of Mineralogy, 6th edition, and to Egleston's Synonyms. To avoid useless repetition, reference to these works will therefore be omitted in the immediately following pages, except in special cases.

when bedded in clays is often in irregular blocks or masses with smooth surfaces and rounded edges coated with the oxide or carbonate; it also occurs in a granular condition loose or disseminated through rock, sometimes cementing sand grains in nodules; the crystals are sometimes in skeleton "reticulated" forms and partially decomposed. It is rarely fibrous.

As occurring in nature, galenite is generally formed from solution, probably through the reduction of sulphate of lead by organic matter, also through the action of sulphide of sodium upon a soluble lead silicate in the presence of an alkaline carbonate. [*199, p. 318.*] Artificially it is formed by distillation in furnaces, by heating the oxide or silicate of lead with vapor of sulphur, by the action of decomposing animal matter on lead sulphate in water saturated with carbonic acid [*9, p. 50*], by passing steam over lead sulphide at a white heat. [*39, vol. iv, p. 387.*] It may be precipitated from a solution of a chloride by hydrogen sulphide or by an alkaline sulphide. [*91, vol. ii, p. 485.*]

Cerussite.

Syn.: Lead carbonate, white lead ore, dry bone, wool mineral, black lead ore, black lead spar, diprismatic lead baryt, spar, earthy lead spar, lead earth, native glass of lead, zinc lead spar.

Var: Iglesiasite (with Zn), phosegenite (with $PbCl_2$), hydro-cerussite, leadhillite (lead carbonate and sulphate).

This compound is of variable appearance, ranging in color from white through gray into black, sometimes tinged blue or green by salts of copper. Luster adamantine to vitreous, sometimes sub-metallic. Sp. gr. 6.46 to 6.57; hardness 3 to 3.5. Very brittle, with conchoidal fracture. It crystallizes in the orthorhombic system, in tubular, prismatic and pyramidal forms, twins very common; crystals in aggregates. Distinct cleavage.

It is composed of lead oxide 16.5 parts, and carbon dioxide 83.5 parts ($PbCO_3$) containing 77.5 per cent of lead. It generally contains small quantities of silica, iron and other impurities. It is soluble in dilute nitric acid with effervescence, and to some extent in water.* [*14, vol. iii, p. 468.*]

Cerussite is generally found massive, earthy and compact in irregular, rounded shapes; it is often granular, rarely fibrous, also stalactitic and in pseudomorphs; also gray and ashy in cavities, and coating galena.

---

* In 50816 parts of carbonated water. [*14, vol. iii, p. 511.*]

It is usually formed from the oxidation of other lead compounds, generally galenite, which, probably, is first changed to the sulphate, and the latter compound then converted into the carbonate by percolating waters holding earthy or alkaline carbonates in solution. Artificial lead carbonate is formed by the action of an alkaline carbonate on a lead salt in solution; also by the action of carbonic acid upon the basic acetate of lead, and in other ways.

Hydrocerussite, a closely related compound, differs from it by containing 2.3% of water. It occurs very sparingly as a coating on native lead in Sweden.

Anglesite.

Syn: Sulphate of lead, lead vitriol, lead mineralized by vitriolic acid.

Var: Linarite (with Cu), hydrous anglesite, caledonite (basic sulphate of lead and copper).

It is of white, pale yellow, green or blue color, with adamantine or resinous and vitreous luster, transparent to opaque. Sp. gr. is 6.12 to 6.25, hardness 2.75 to 3. It is very brittle, with a conchoidal fracture. Cleavage is distinct, but interrupted. It crystalizes in the orthorhombic system, often prismatic, sometimes tabular, also pyramidal.

It is composed of sulphur trioxide 26.4 parts, and lead oxide 73.6 parts ($Pb\ SO_4$), containing 68.3 parts of lead.

Anglesite is soluble in citrate of ammonia, difficultly soluble in nitric acid, slightly soluble in large quantities of water.*

It is changed by alkaline carbonates to carbonate of lead; it is dissolved by hot ammonia, but reprecipitated when cold. Ammonia salts also dissolve it more or less [*162, p. 84*]; it is fusible at a high temperature.

Anglesite is found in crystals in cavities of galenite crystals, sometimes stalactitic, also massive, granular to compact, in nodular forms, often surrounding a nucleus of galenite in concentric layers.

In nature anglesite is generally formed by the direct oxidation of the sulphide of lead, galena; artificially lead sulphate is precipitated from a solution of a lead salt by sulphuric acid or by a solution of a sulphate.

---

* For 22,816 parts of water [*14, iii, p. 465*].

At 11°C ..... .0004583 in 100 parts water.

At 18°C ..... .0003155 in 100 parts of water.

V. Roth, quoted by Emmons [*78, p. 551*].

Pyromorphite.

Syn.: Phosphate of lead, green lead ore, brown lead ore, brown lead spar, green lead spar, pencil stone, rhomboidal lead spar.

Var.: Polysphærite with sub-varieties, miesite, cherokine, nussierite, all containing lime. Chromiferous and arseniferous varieties also exist.

The color is of various shades of green, yellow and brown, sometimes grayish white. Streak white. Translucent. The hardness is 3.5 to 4; Sp. Gr. 6.5 to 7.1 when pure. It is brittle with an uneven fracture. Crystallizes in the hexagonal system in prismatic forms in branching groups, often barrel-shaped. It is composed of lead phosphate 89.7 parts, and lead chloride 10.3 parts [$(Pb\,Cl)\,Pb_4\,P_3\,O_{12}$], containing thus 76.3 per cent of lead. Small quantities of lime are frequently present, and, at some localities, arsenic is common, and elsewhere chromium; small percentages of iron are generally contained. When not in crystals it is often globular, reniform and botryoidal, also fibrous and granular, massive and earthy, as a coating on cerrussite. It fuses easily (F. 1.5); it is soluble in nitric acid.

Minium or Lead Oxide.

It is amphorous and pulverulent, occasionally exhibiting crystalline scales under the microscope. Opaque of red and yellow colors, with an orange streak. Dull luster. Hardness 2 to 3; Sp. Gr. 4.6. It is composed of oxygen 9.4 parts and lead 90.6 ($Pb\,O$). In nature it is derived from galena; artificially it may be obtained in small crystals by heating lead carbonate in a ball of potassium and sodium nitrate at 300°C. It melts at a red heat. Very slightly soluble in water.

Minor Compounds.

In addition to these ore-forming compounds of lead, there is a large number of other compounds of comparatively rare occurrence. Prominent among these are:

Chromates.—These include crocoite, a red chromate of lead which is found sparingly in prismatic crystals; phoenichroite, a red or yellow basic lead chromate; and vanguelinite, a green to brown phosphochromate of lead which occurs in monoclinic crystals and in mammillary concretions.

Molybdates.—Wulfenite is the only important molybdate of lead; t occurs in tabular crystals of the tetragonal system and is generally of yellowish color. It is not of infrequent occurrence in small quantities.

Antimonates.—Monimolite is an antimonate of lead, iron and sometimes calcium. It occurs usually in octahedrons of yellow or greenish

colors. Bindheimite is an amorphous, hydrous antimonate, of white to brown color.

Arsenates.—Mimetite is the most common lead arsenate and occurs in hexagonal crystals and rounded forms; it is of a pale yellow to brown color. Other rarer compounds are carmetite, a lead and iron arsenate, and balydonite, a lead copper arsenate. Ecdemite is an arsenate of rare occurrence.

Oxides.—Massicot is the lead monoxide of not very rare occurrence; it is massive, earthy or crystalline, of yellow and sometimes red color. Minium, the combined monoxide and dioxide is a comparitively familiar compound which occurs generally in a pulverulent condition, and of a vivid red color.

Silicates.—Barysilite, ganomalite and hyalotekite are silicates of lead which have been identified principally at Wermland, Sweden; they occur sparingly, mixed with other minerals.

Sulphantimonites.—Zinkenite is found at several localities in orthorhombic crystals and massive, of a steel gray color and metallic luster. Jamesonite is of similar appearance and composition. Bournonite, containing copper and lead, is also in orthorhombic crystals and of metallic luster and steel gray color. Less known sulphantimonites are plagionite, warrenite, boulangerite and others.

Sulphato-carbonates.—Leadhillite, commonly a white or yellowish compound occurring in tabular crystals of the monoclinic system, and found in small quantities associated with lead ores.

Sulpho-bisumites.—Galenobisumthite, cosalite, kobellite are the most prominent, though several others are known.

Vanadates.—The combined vanadate and chloride of lead, vanadinite, is probably the best known—a red or yellowish mineral found at a large number of localities, often associated with wulfenite; descloizite is another of much mineralogic interest, and there are several more.

In addition to these there are several other compounds, such as chlorides, oxychlorides and sulpharsenites, which we will pass by without further mention. Some of these minerals are of quite frequent occurrence, but this is generally in small quantities in rocks or as accessory constituents of ore bodies; none are to be classed as sources of lead supply.

THE NATURAL COMPOUNDS OF ZINC.

Native Zinc.—The occurrence of the metal in nature is doubtful, though it has been reported in Australia and in Georgia and California of this country.

Sphalerite.

Syn.: Zinc sulphide, blende, pseudo-galena, false galena, steel blende, mock lead, sulphuret of zinc, zinc blende, black-jack, jack, rosin-jack, speckle-jack, pebble-jack, garnet blende, ruby blende, radiated blende, wild lead, strawberry blende, mock-jack, brazill.

Var.: Przibramite (with Cd), wurtzite (hexagonal), cleiophane (pure white), rahtite (with Cu), mariatite and marmatite (with Fe), plumbiferous blende, marasolite (with free S), mercurial blende.

When pure, sphalerite is nearly colorless, but as commonly found, it is yellow, brown or black; it is also found yellow and green and of a bluish lead color. The streak is brown to white. It is transparent to translucent, with a resinous to adamantine luster. Brittle, with a conchoidal fracture. Hardness is 3.5 to 4; S. Gr. 3.9 to 4.1, but at the highest temperature of the assay furnace it appears to volatilize without fusing [*165*]. It is practically infusible. Sphalerite crystallizes in the isometric system in dodecahedral forms, often twinning, the crystals being frequently highly complex and distorted.

The composition of sphalerite is sulphur 33 parts and zinc 67 parts ($Zn\,S$), but it often contains impurities, such as iron and manganese and sometimes lead, copper and cadmium, and other metals more rarely. It is sometimes argentiferous.

This mineral is decomposed and dissolved slowly by hydrochloric and sulphuric acids; more actively by nitric acid. Digested for several hours in a concentrated solution of potash, it dissolves completely [*197, p. 61*].

Sphalerite occurs in imperfect crystals, isolated or in clusters, embedded in clay or orther matrix, disseminated in rock, or attached to surfaces of walls in cavities as crystals or stalactites; it is often massive and cleavable, also granular, coarse to fine and compact, sometimes foliated, fibrous or radiated, in scales, also botryoidal; at Galena, Kansas, and near Joplin, Missouri, it has been found in a soft pure white clayey condition as redeposited from solution. Cubical crystals of blends have never been formed artificially, but wurtzite crystals have been in several ways. Senarmont produced such by heating the

sulphide in H_2S under great pressure. Crystals have also been formed by volatilizing the sulphide [*197, p. 59*].

In nature, this mineral is probably generally formed from solutions of the sulphate, through the intervention of organic matter or some other reducing agent. Artificially it has been prepared in a similar way by the action of putrefying oysters on a solution of the sulphate, the shells becoming converted in part into carbonate of zinc incrusted with some sphalerite; it may also be prepared by heating the oxide or silicate in vapors of sulphur. It seems also to have been formed by volatilization and recondensation [*39, vol. iv, p. 388*]. Zinc combines directly with sulphur with difficulty and violence; finely divided zinc and sulphur compresssed three times in succession under 6500 atmosphores produced a block resembling sphalerite. The oxide, sulphate and carbonate heated with sulphur yield the sulphide readily [*197, p. 55*].

Sulphuretted hydrogen precipitates a white, hydrous sulphide from solutions of weak acids, like acetic; if an excess of acetic acid or of acetate of soda be present, the precipitation is complete from solution of any salt. The white sulphide thus precipitated is soluble in mineral acids, but insoluble in alkaline sulphides as well as in caustic alkalies and all saline carbonates. Alkaline sulphides and sulphates in general precipitate the white sulphide [*197, p. 131*].

Calamine.

Syn.: Zinc silicate, electric calamine, hydrous silicate of zinc, zinc calamine, galmey, prismatic calamine, prismatic zinc barite, siliceous calamine, siliceous oxide of zinc, smithsonite, vanuxemite, zeolite of Breisgau.

Var.: Wagite (concretionary, light blue), carbonated, argillaceous, moresnetite (with Al, Fe and Ni), vanuxemite (mixture of silicate and white clay).

The color, when pure, is white; it is also yellowish to brown and sometimes of a bluish tint. It is transparent to translucent, with a vitreous and adamantine luster. Cleavage with certain faces perfect, along others less so. Fracture uneven. Hardness is 4.5 to 5 and sp. gr. 3.40 to 3.50. The streak is white. It is almost infusible (F. 6). Is strongly pyroelectric.

It crystallizes in the orthorhombic system in hemimorphic and highly modified forms. Crystals often tabular, also prismatic and often grouped in sheaf-like forms.

Calamine is composed of silica 25.0 parts, zinc oxide 67.5 parts, water 7.5 parts (H_2O, $2ZnO$, SiO_2); it thus contains 54.2 per cent of

zinc. As above indicated, it sometimes is mixed with clay as an impurity, and also contains small quantities of iron and other foreign ingredients.

It gelatinizes with acids, and is decomposed by acetic acid with gelatinization. Also by carbonic acid, forming the carbonate [*14, vol. ii, p. 60*]. It is soluble in a strong solution of caustic potash.

According to Bischof [*14, vol. iii, p. 444*.], the artificial silicate is so sparingly soluble in water "that its presence is not recognizable by sulphide of ammonium. It requires for solution 185,440 parts of water. The native silicate dissolves in 3,692 parts of water saturated with carbonic acid. Monheim that states it dissolves without decomposition in carbonated water, and it has probably been deposited from such solutions."

Calamine occurs in mammillary, botryoidal, stalactitic, fibrous and massive and granular forms; also in crystals in sheaf-like aggregates lining surfaces of cavities; it is found attached to rock and also in masses imbedded in clay.

In nature this mineral generally results from the decomposition of blende, probably through the reaction of the comparatively soluble sulphate or of the carbonate of zinc and some soluble alkaline silicate.

Smithsonite.

Syn: Zinc carbonate, dry bone, calamine, rhombohedral calamine, rhombohedral zinc baryte, zinc spar, white jack.

Var.: Monheimite (ferriferous), capnite, turkey fat ore (yellow, with Cd S), orthorhombic zinc carbonate (with FeO, SiO_2 and other oxides). herrerite (cupriferous).

The color of smithsonite is normally white, but it is often gray and sometimes tinged yellowish, brown and even green or blue from impurities. The variety turkey fat ore is of a brilliant yellow color. The luster is vitreous, but less brilliant than calamine; it is translucent and has a white streak. It is brittle, with an uneven fracture; the hardness is 5 and the specific gravity 4.30 to 4.45. It crystallizes in the rhombohedral system, though rarely in perfect forms, the faces being generally curved and rough.

When pure, smithsonite is composed with carbon dioxide 35.2 parts, and zinc protoxide 64.8 parts ($Zn\ CO_3$), thus containing 52.03% of metallic zinc. It often contains carbonates of iron and manganese as well as of calcium and magnesium; cadmium is also not infrequently present. It is often intimately mixed with the silicate, calamine, and sometimes with clay or earthy impurities. It is readily soluble in

hydrochloric and other acids with effervescence; also in potash. It dissolves in 4108 parts of water saturated with carbonic acid [*14, vol. i, p. 15*].

Smithsonite usually occurs in reniform or botryoidal masses, also stalactitic, pseudomorphous and in incrustations; also, granular, cellular and sometimes earthy, often closely resembling similar forms of the silicate.

The mineral is generally formed in nature by the action of carbonated waters upon sphalerite, the latter probably being first oxidized to the sulphate; in a pulverulent form it is produced from the decomposition of the oxide zincite. It may also result from the action of carbonic acid upon the silicate of zinc. The basic carbonate is precipitated from a solution of zinc salts by three of the carbonates of soda.

Hydrozincite.

Syn.: Hydro-carbonate of zinc, calamine, earthy calamine, zinc bloom, marionite, ceganite, zinconise.

This mineral is of white, gray or yellowish color, usually earthy and with a dull luster; the streak is, however, shining. The hardness is 2 to 2.5 and the specific gravity 3.58 to 3.8. It is amorphous. The composition is not exactly determined and analyses differ somewhat; as expressed by Dana it is, perhaps, $Zn\ CO_3\ 2\ Zn\ (O\ H)_2$ or $3\ Zn\ O\ CO_2$, $2\ H_2O$, containing carbon dioxide 13.6 parts, zinc oxide 75.3 parts and water 11.1 parts, equivalent to 60.47 per cent of metallic zinc. Small quantities of lead and traces of iron and silica are sometimes present. Like smithsonite, it is readily soluble in hydrochloric and other acids with effervescence.

Hydrozincite occurs in an earthy form, also massive and fibrous, in concentric crusts and stalactites, nodular, concretionary, botryoidal and pisolitic. In nature, it is generally a decomposition product from blende, smithsonite or calamine. Artificially it is formed through the decomposition of hot solutions of zinc salts by alkaline carbonates.

Zincite—

Syn.: Oxide of zinc, red zinc ore, spartaliogite, prismatic zinc ore, red oxide of zinc, brucite.

Var.: Calcozincite (with calcite).

The color is deep red or orange, though artificially produced crystals have been found of a white to amber color. Its luster is almost adamantine and it is translucent. Streak orange yellow. It is brittle and the fracture is subconchoidal. It crystallizes in hemimorphic

forms of the hexagonal system. Hardness is 4 to 4.5, and specific gravity 5.43 to 5.7. It is infusible and slightly volatile. It is composed of zinc 80.3 parts and oxygen 19.7 ($Zn\,O$); oxide of manganese and small quantities of ferric oxide are sometimes present. It is reduced at a red heat by carbon, potassium and iron.

Zincite generally occurs in foliated or lamellar masses, or granular and in coarse particles; it is also reported pseudomorphous after sphalerite.

As occurring in nature this compound of zinc is an original product and does not result from the decomposition of other ores. Artificially, crystals are formed in furnaces by distillation. In the arts the oxide is prepared by heating the metal, a white powder being the result. It is soluble in acids without effervescence, and is insoluble in water. It is also soluble in alkaline aqueous solutions of ammonia, potassium and sodium, forming zincates [*197, p. 44*].

Willemite.

Syn.: Anhydrous silicate of zinc, silicate of zinc, silicious oxide of zinc, williamsite, brachytypous zinc-barite.

Var.: Troostite (reddish crystals with Mn) tephrowillemite.

When pure, willemite is of a white or greenish color, but from various impurities it may be of different shades of gray, yellow, brown or red. The streak is white. It is of resinous luster and transparent to opaque. The fracture is uneven and brittle. Hardness is 5.5 and the specific gravity 3.89 to 4.18. It crystallizes in rhombohedral forms, commonly in hexagonal prisms, either long and slender or short and stout. It is composed of silica 27 parts and zinc oxide 73 parts ($Zn_2\,SiO_4$), containing thus 58.62 per cent of metallic zinc. With this there is often manganese in considerable quantity and some iron; traces of magnesium and calcium oxide are also present at times. It is decomposed by hydrochloric acid with the separation of gelatinous silica.

This mineral is found in nature in crystals, and also massive in grains and fibrous. It has probably been formed like calamine by the action of soluble silicates upon zinc sulphate. Artificially it has been formed by heating a mixture of hydrated silica, sodium sulphate and zinc sulphate; also at a red heat from zinc oxide and fluoride of silicon. It has also been observed in furnace slags.

Minor compounds.—Other less common compounds of zinc, which are of little or no commercial importance, are quite numerous; a few of the more prominent are:

Sulphates.—Goslarite is a hydrous sulphate of zinc, found quite frequently, but not abundantly. It is a decomposition product of blende. It occurs generally in small white crystals encrusting minerals or rocks. It is soluble in water and in dilute alcohol.

An anhydrous sulphate of zinc exists, though very rare in nature. It has been found in Barranco Tarosa, Spain. It is decomposed by heat, and is very soluble in water.

Aluminate.—Gahnite or zinc spinel is a quite well known zinc aluminate, occurring at several localities in this country and Europe. It is found in octahedral crystals of greenish, gray or yellowish colors with a vitreous luster. A number of varieties are recognized.

Arsenates.—Adamite appears to be the least rare of these and is found in orthorhombic crystals of yellow, reddish and green colors. Kœttigite and veszelyite are rarer arsenates.

Ferrate.—Under this class, Dana includes the mineral franklinite, which, though common at a few localities in New Jersey, is otherwise very rare. It is found in octahedral forms, and also granular and massive, of a black color and metallic luster, containing manganese.

Still rarer compounds are the phosphate, hopeite; the sulphate, sinkosite, of doubtful identity, found in Spain, and a zinc-aluminite found at Laurium, the oxysulphide, voltzite, and possibly a bromide and an iodide.

CHAPTER III.

DISTRIBUTION AND CONDITIONS OF OCCURRENCE OF LEAD AND ZINC.

THE DIFFUSED CONDITION—THE CONCENTRATED CONDITION.

In the preceding chapter we have described the natural compounds of lead and zinc; in this chapter we shall treat of the forms and conditions under which these compounds occur in nature.

THE DIFFUSED CONDITIONS.

Lead and zinc, though of less common occurrence and apparently much less widely diffused than some other metals, such as iron and manganese, are, according to recent researches, more generally present than has been supposed, though often in exceedingly minute quantities. While the more common metals constitute a large portion, or at least several per cent of a rock, these two metals are represented by small fractions of a per cent, often passing to the third and fourth decimals.

In Rocks.—Forschhammer [*88, p. 60*], working on one pound samples, long since showed the presence of minute quantities of the heavy metals in Scandinavian rocks which were not associated with ore deposits. He also found considerable quantities of lead, zinc and copper in slates of Bangor, Wales [*88, p 60*]. According to Dieulafait [*68, p. 256*], zinc is diffused in all ancient rocks, such as porphyries, granites, gneisses and schists. Bischof found traces of lead in clay shales of Lobenstein, while Sandberger has found lead, zinc and other metals in the non-siliceous clay shales of the neighborhood of Holzappel and at Ems, as well as in shales of Schulenberg near Clausthal. Lead was also found in clay shales at various horizons of the *Keuper* or Upper Trias, and even in ferruginous nodules of sandstone. Bituminous marly shales of Raibl were found rich in lead and zinc, and limestones of all horizons of the "*Muschelkalk*" or Middle Trias hold

lead, zinc and copper [*199, pp. 32-34*]. In the ash of coal from Berwick, Scotland, Richardson found 2.03% of ZnO, along with other metallic oxides [*197, p. 3*].

Coming nearer home, Emmons found lead to be a constituent, in minute quantities, of nearly all specimens of porphyries and other crystalline rocks from about Leadville [*78, p. 578*], though only one sedimentary rock, a sandstone, was found to contain that metal. Mr. Robertson's analyses of Missouri limestones, granite, porphyry and diabase, introduced and discussed in chapter XII, reveal the almost constant presence of both lead and zinc.

These facts, though resulting from a comparatively limited number of analyses of specimens representing only a small portion of the earth's crust, yet make the expectation warrantable that similar investigations, applied to other localities, will yield similar results. The quantities of these metals present are too small to have been detected by the ordinary methods of analysis with samples of ordinary bulk. Large quantities and special precautions must be used. When such investigations are widely extended, we are of the opinion that the general diffusion of small quantities of these and other metals will be demonstrated.

In minerals.—This conclusion is further substantiated by the fact of the occurrence of both lead and zinc in a large number of minerals of which they are not essential constituents. Thus, zinc, according to Dana, has been found as an accessory constituent in some 40 different mineral species, in quantities generally less than one per cent, but ranging from a trace and .04 per cent to over 11 per cent of Zn O.

These are: Stannite, galenobismutite, berthierite, schermerite, jamesonite, brongniardite, bournonite, wittichenite, tennantite, polyargyrite, several sulpharsenates and sulph-antimonates, periclase, wad, calcite, dolomite, rhodochrosite, jeffersonite, jadeite, fowlerite, tephroite, schrotterite, chrysocolla, bementite, vanadinite, erenite, clinoclasite, conichalcite, tyrolite, mixite, caracalite, antlerite, romerite, glockerite, samarskite.

Lead is similarly found in some 20 different species, its less frequent presence being doubtless because of the less solubility of the salts of lead.

These are: Metalonchidite, sylvanite, mullerine, chalcostibnite, miargyrite, binnite, wad, vesuvianite, yttrialite, chrysocolla, caryopilite, columbite, hielmite, xenotime, sarkinite, pinakiolite, montanite, samarskite.

Were the analyses of minerals generally sufficiently refined to determine the presence of quantities of these metals not exceeding a

few hundredths of one percent, the list of minerals would undoubtedly be much larger. Sandberger has shown the probability of this by his analyses of large bulks of various rock-forming minerals. In the augites of diabases, melaphyres, basalts, etc., of some localities, such as the Andreasberg in the Harz, he found considerable quantities of zinc and lead, also in hornblendes; in olivenes zinc was found only occasionally. Black micas he found especially rich in lead and zinc, notably in those of the older gneisses of the Erzgeberge, of the granites of Andreasberg and Heidelberg, of gneiss of Kinzig, that in the southern Black forest and of the propylite of Schemnitz. Generally he found the minerals of the younger rocks richer in metals than those of the older [*199, pp. 23–26*].

In Waters.—According to Bischof [*14, pp. 109–110*], Malaguti, Durocher and Sarzeaud found minute quantities (1 mgr. in 100 liters) of silver in sea salt, rock salt, and even in sea water, in the channel of St. Milo. Lead was not found in the water, but both it and copper were detected as chlorides in the ashes of sea plants; the former in the proportion of .000018. Forchhammer's analyses, however, show that ocean salt contains lead, zinc and other metals in very minute quantities [*69, p. 610*]. An analysis of the water of the Frith of Forth showed that the residue from 2 kilogrs. of the water contained lead in the proportion of .0000975 and about half as much copper [*127, p. 604*]. Dieulafait found in water of the Mediteranean 1.6 to 2.0 mgs. of zinc to the cubic meter [*68, p. 256*]. Analyses of manganese nodules found in deep sea deposits gave—0.10% of Zn O and 0.05% of Pb O. [*40, vol. xlvi, p. 417*].

In ordinary mineral waters salts of these metals have not often been detected, yet their presence is shown in some cases. Thus Will's analyses show .0104 grams to .0076 grams of bicarbonate of zinc to 1 liter of water from three springs of Nauheim in Hesse Darmstadt; other waters from the same neighborhood show from traces up to .007 grams of bicarb. of zinc and traces of oxide of lead and other metals [*101, pp. 382, 385*]. Sandberger refers to oxides of lead and zinc and of other metals deposited at the surface from mineral springs in the Black forest and also at Kissingen. The insoluble residues of the dolomite from which the waters at the last place flow, yielded lead, zinc, arsenic, nickel and cobalt [*199, pp. 5-6*]. According to Lersch, lead occurs in the spring waters of Rippoldsau (.0000016 to .0000037 grams per liter) of Kissingen (.00001 to .000013 grams), Alexisbad, Ems, Hamburg

and Karlsbad [*141*]. In Pennsylvania Genth detected .01 grains per gallon of zinc carbonate in the waters of Minnequa springs; in Virginia Mallet, Hardin and others detected .03 to .61 grains per gallon of zinc sulphate in the Jordan Alum spring, and .12 grains zinc sulphate and a trace of lead sulphate in the water of Rockbridge spring [*163, pp. 46, 62, 64*]. Deposits from the waters of Steamboat springs, Nevada, according to G. Becker, contain .0038% of lead and traces of zinc and other metals; but analyses of the waters did not reveal these metals, though the more abundant metals, antimony and arsenic, were found.

In Plants and Animals.—As suggesting a further line for investigation, it may be noted that zinc has been found in the ashes of the yellow violet (*Viola calaminaria*) in Rhenish Prussia. [*194, Vol. ii, pt i, p. 225.*] Forschhammer found it in marine plants *Zostera maritima* and *Fucus vesiculosus.* Lechartier and Bellamy found zinc in grains of corn, barley, maize and in haricot beans; also in hen's eggs, in beef and in calf's liver and human liver. [*197, p. 3.*]

These facts indicate the diffusion of the metals under consideration; their familiar and economically important modes of occurrence are, however, as recognizable mineral compounds in local aggregates, known as ore deposits. These may be large or small, may be irregular masses, may be flat vertical sheets commonly called veins, may consist of crystals disseminated through rock masses, may be associated with rocks of various ages or of various modes of formation. As thus occurring these metals are, however, of more limited distribution, geographically and geologically.

This condition of occurrence we will now proceed to consider.

THE CONCENTRATED CONDITION.

The ores of lead and zinc which we have described occur in nature aggregated in bodies of various forms and with various associations; they are, moreover, not universally distributed, but are confined to certain localities or regions, and characterize certain geological formations more than others. These bodies of ores, for lack of a better English word, we term collectively, "Ore Deposits."

As stated in the preceding chapter, we distinguish as ores those compounds, or mixtures or associations of lead and zinc compounds, which are of commercial importance as sources of supply. Likewise,

we define as ore deposits those aggregates which are not only composed of lead and zinc ores, but in which these ores are found in sufficient quantities and under conditions suitable for mining. It is avowedly a relative term, and this definition is not to be applied too rigidly; no hard and fast line can be drawn; it is intended to eliminate from consideration such classes of occurrences of these metals or of their compounds as experience teaches us cannot be profitably exploited. Thus, we have seen that lead and zinc occur diffused in minute quantities through various rocks, and are found in sea water, yet we would not class these rocks nor sea water as ore deposits. On the other hand, many veins and other aggregates of these ores may not contain sufficient quantities to pay for working; yet these aggregates belong to classes which are often sources of supply, and hence these "lean" individuals are not denied consideration.

THE CLASSIFICATION OF LEAD AND ZINC DEPOSITS.

Classification of objects is their grouping according to common characteristics constituting relationships. Objects are thus related to each other in various ways and as regards various attributes. Ore deposits may be classified according to the metals contained, the composition of the metallic compounds, the associated minerals, the form or shape of the deposit, the structure of the deposit, the nature or the age of the rocks in which they occur, their attitudes in the rocks, their geographic distribution, the mode of formation of the metalliferous constituents, or of the ore body apart from these, the source of the metals, and even according to age of formation of the deposit.

These considerations are all of importance, but a classification according to some of them would be very artificial. Exact knowledge regarding all we do not possess and may never acquire. Were we in possession of such knowledge, however, it would be difficult to provide for all or many of these considerations satisfactorily under one scheme, in what could be called a natural classification. The attempt to do this without full knowledge has been the cause of much confusion in the past, and has burdened the literature of the subject with a long array of schemes and with a still longer series of discussions. Different ends may demand different bases of classification. Which basis or principle may be best for common use we are not prepared to

say. Once the controlling principles decided upon, however, incongruous considerations should not be allowed to enter. *

The considerations of most practical as well as scientific value controlling the classification of lead and zinc ore deposits are the following:

1. The composition of the metalliferous constituents.
2. The mode of formation of the metalliferous constituents.
3. The source of the metalliferous compounds.
4. The form or shape of the ore body.
5. The altitude of the ore body.
6. The structure of the ore body.
7. The mode of formation of the ore body.
8. The nature of the associated substances.
9. The nature of the enclosing rocks.
10. The age of the enclosing rocks or the geological position of the deposit.

The deposits of lead and zinc ores we will briefly consider under these headings, referring the reader for special detail to the descriptions of noted occurrences given in the chapters on the distribution of these ores. Our remarks in this discussion can, fortunately, in almost all cases, be made to apply equally well to the deposits of lead or of zinc, for the condition of their almost constant association in Missouri which gave rise to this dual report is a world-wide phenomenon.

1. The Composition of the Metalliferous constituents.—It is an interesting fact, and one to be noted, that almost all important deposits of either lead or zinc ores contain the same compounds or group of compounds of these metals; these are: 1. the sulphides; and 2. their oxidation products, the carbonates and silicates and other less important minerals. Exceptions to this rule are the remarkable deposits at Franklin furnace and Sterling, New Jersey, which consist of a mixture of the ferrate, franklinite, the oxide, zincite, and the anhydrous silicate, willemite.

A subdivision of these deposits into those consisting of sulphides and those consisting of their oxidation products does not commend itself, inasmuch as both classes are represented in almost all deposits;

* An excellent summary and comparison of the more important classifications of ore deposits is given in Prof. Kemp's recent work on The Ore Deposits of the United States [252]. Since then Prof. W. O. Crosby has published a classification based on origin and original structure [254], which is eminently logical, and which commends itself for adoption by scientific men.

the latter generally preponderate in the upper levels, the former in the lower; the relative quantities of the two are the distinguishing features. The only logical and practical classification, therefore, seems to be:

A. Deposits of sulphides and their oxidation products, represented in nearly all important mines of these ores.

B. Deposits of the ferrate and oxide, of which the New Jersey deposits are types, and the only noteworthy instances.

2. *The Mode of Formation of the Metalliferous Constituents.* The distinction drawn between the mode of formation of the metalliferous constituents and that of the ore body may appear to some more fanciful than real, and consequently unnecessary. It is, however, perfectly well defined, and of direct value in mining practice. The metalliferous contents of two ore deposits may have been formed in exactly the same way, and yet the mode of formation of the ore bodies as a whole may have been entirely different. The mineralization of the brecciated mass constituting the body of a lode may have been by the same process as the mineralization of a stratum of limestone or sandstone, and yet the mass of the material included in what we term the ore body is of entirely different mode of formation. A clear conception of the distinction between the two ideas is necessary for intelligent exploitation.

The zinc and lead compounds in deposits of these ores have been formed almost entirely in two ways:

A. By simple deposition from solution, generally in cavities.

B. By chemical alteration or replacement of solids.

Two other processes have been advanced in the past, i. e., through sublimation and condensation from heated vapors, and by solidification from a fused condition. The latter hypothesis was at once rejected by those at all familiar with chemical laws; the former, though theoretically possible in some cases, is now discarded by authorities who have fully considered all the facts in the case.

A. Lead and zinc compounds are deposited from solution by chemical precipitation, by crystallization, and by evaporation and possibly by cooling or relief of pressure. The galena and blendes of many ore deposits have probably been formed by chemical precipitation in cavities, accompanied by crystallization, through the reduction of the soluble sulphates by organic matter. Illustrations of pure crystallization from solutions without chemical reaction are furnished by lead

sulphate and carbonate, and by zinc silicate and carbonate, which probably often separated out without change in composition, either as isolated crystals or in crystalline masses. In some cases galena and blende crystals may have been formed in the same way. As instances of formation by evaporation, we may cite the stalactites of smithsonite, cerussite, and perhaps even of sphalerite, which are quite frequently found. Ores formed by these processes are represented in almost all extensive lead and zinc deposits. They are found in greater or less abundance in the Mississippi valley, at Carinthia in Austria, at Bleiberg in Belgium, in the North of England, and in the Cornwall lead mines, at Mechernich and Wiesloch in Baden, at Laurium in Greece, and in Sardinia.

B. Metalliferous compounds formed by the chemical alteration or replacement of solids include the sulphides, as well as those ores of lead and zinc which are classed as alteration or oxidation products. The latter are principally the carbonates and silicates, though the sulphates, oxides and phosphates may be included. They are generally formed by the chemical action of acids, or of oxygen held in waters derived from the surface, upon the sulphides of these metals. Where these alteration products are taken into solution and redeposited, perhaps at another point, as is probably often the case with the zinc compounds, they are doubtless frequently to be classed with the compounds deposited in cavities from solution; but where they replace the sulphides without prior solution, they belong to this last class. Where the sulphides or oxidation products replace other substances, such as limestone or calcite, we conceive that a particle of the replaced material must be removed before the corresponding particle of the metallic compound can occupy its place, and thus, in a minute sense, a deposition from solution in a cavity takes place. But this is so different from the normal conception of the first process, and the resultant ore bodies are so different in form, structure and texture, that a separation is demanded. Many of our most productive ore deposits in both this and other countries have probably been formed by this process. Instances of such are those of Leadville, Eureka, some in Montana and those of Southeastern Missouri, in our own country. In Europe are the smithsonite deposit of Carinthia, the zinc ores of Vieille Montagne, in Belgium, of Upper Silesia, of Iserlohn in Westphalia, of Wiesloch in Baden, perhaps, of Laurium in Greece, of Les Avinieres of France, of Sardinia, and of Carthagena and Santander in Spain.

3. The Source of the Metalliferous Compounds.—To satisfactorily classify lead and zinc deposits on this basis would necessitate the settlement of many mooted questions; probably on no one subject relating to ore deposits has there been so much discussion and are authorities yet so much at variance. Broadly speaking, and with reference only to the *immediate* source of supply, the theories worthy of consideration may be grouped under the two following heads:

A. Derivation of ores from great depths through the medium of ascending solutions.

B. Derivation from the country rocks by segregating action or lateral secretion through the medium of circulating waters.

A. By derivation from great depths is meant depths where extraordinary concentration of metalliferous bodies may exist, or where the conditions of temperature and pressure are such that many substances are taken into solution which would not be much affected under the conditions prevailing near the surface. The relief of pressure and the diminution of temperature with the ascent of the solutions are considered causes of first importance controlling the deposition of the metals or of their compounds. As the source of the ores of many deposits remains yet unsettled, examples cannot be cited with confidence. As a general rule, those bodies occurring in well-defined fissures, which are recognized to extend to great depths, those which are associated with intruded igneous rocks or with thermal springs, especially if in regions of volcanic activity, are more probably assignable to such source.

B. The support for the second theory of derivation from the country rocks is derived principally from the facts already introduced in chapter II, that small quantities of these metalliferous compounds are found diffused through rocks. Hence, it can readily be conceived that they may be brought together through the aid of circulating waters, whether accompanied by the decomposition of the rocks or not. Those deposits not occurring in strong and deep fissures, and those remote from intruded igneous rocks or other volcanic phenomena, are more probably of this class.

4. The Form or Shape of the Ore Body.—In classifying by form we are forced to refer to geometrical figures. But ore deposits never have such regular outlines that they exactly represent such figures; they at best only approximate these; from this it follows that the forms

of one class merge into those of another. With reference purely to shape, we recognize the following classes of lead and zinc ore bodies:

A. Tabular or sheet deposits.

B. Lenticular deposits.

C. Cylindrical or pipe deposits.

D. Massive deposits of regular or irregular shapes.

A. By tabular or sheet deposits are meant such ore bodies as occur in sheets, the third dimension or thickness being very small as compared with the length and breadth, which may be of great and undetermined extent. Among these are to be classed what are commonly called veins or lodes. There are sheets of ores and associated minerals occupying fissures or crevices in the country rock. Instances of such are almost too numerous to mention. They are represented in the United States by the veins of Franklin county, Missouri, by those of New York and Connecticut; in Europe by those of Przibram in Hungary, of Bleiberg and Welkenradt in Belgium, of Shropshire and Cornwall in England, of Rammelsberg in Germany, of Les Malines and Pontpean in France, by the veins of South America, southern and central Mexico, and a host of others. Here also belong, in part at least, what are known as interbedded deposits, which consist of sheets of ore lying between different layers of stratified rocks. Such a bed is the franklinite deposit of Mine Hill, New Jersey. Strata of limestone or other rock impregnated over large areas with lead or zinc minerals are also to be included here, when the thickness of the stratum is comparatively small.

B. Lenticular deposits, as the name denotes, are lens-shaped. They are bodies of ore of which the thickness in the center is considerable as compared with the length and breadth, and from this central portion gradually diminishes toward the limits of the body. As is evident, this form grades into the tabular on the one hand, and into the massive on the other; in fact, some veins are made up of a succession of such lenses in the same plane. Typical examples of lenticular lead and zinc deposits are some of those to be described in Southeastern Missouri, some of Carinthia, of Kirlibaba in Hungary, of Wiesloch in Baden, of Laurium in Greece.

C. Cylindrical or pipe deposits form a comparatively unimportant class. Their dimensions are sufficiently indicated by the name, and the diameter does not generally exceed a few feet. They are found, principally, in limestones, and are known as pipes or chimneys. Examples

of these are found in Southeast Missouri and Virginia; in the north of England lead mines, in Upper Silesia, at Wiesloch and at Laurium.

D. By massive deposits are meant bodies of ore of which no one dimension is many times greater than another. They are, properly, large masses of ore, but small bodies, such as occur in "pockets" in many rocks, might, strictly speaking, be included here also. As stated, their shapes may be regular or irregular: that is, they may be, approximately, spherical or ellipsoidal, or their outlines may be extremely sinuous or jagged or may be ill-defined, the ore body gradually merging into the country rock. The essential attribute is that no one dimension of the ore body specially preponderates. Many of our most important lead and zinc deposits, and especially the former, are included in this class. Such are those of Leadville and Aspen in Colorado, of Eureka in Nevada, of Bonne Terre in Missouri, and many of those of Jasper county also. In Europe such deposits as those of Carinthia, Vieille Montagne, Upper Silesia, Mechernich, Wiesloch, Laurium and others.

5. *The Attitude of the Ore Body.*—By the attitude of an ore body is meant the position it occupies with reference both to the horizon and to the plane of stratification, when in bedded rocks. It is of some importance in the quéstion of the genesis of the ores as well as in the question of their probable duration, though considerations of form and dimensions enter at the same time. On this basis the following subdivision may be recognized:

A. Horizontal and gently inclined deposits;

B. Vertical and steeply inclined deposits.

A. Of the first class are most of those deposits which we have referred to and cited as interbedded; generally, also, those impregnating strata. Lenticular and pipe deposits may also assume this attitude, though they are more commonly, perhaps, in other positions. Deposits of this class are common in southeastern Missouri, are found in the north of England, at Truro, Cornwall, at Mechernich, at Wiesloch and at Laurium.

B. To the second class belong pre-eminently those sheet deposits which are known as veins and lodes, and this especially when they are of great length and breadth. The veins of Franklin county are familiar examples of such, and those of the other localities cited on page 36.

6. *The Structure of the Ore Body.*—By the structure of an ore body is meant the arrangement and shape of its component parts. In some instances texture more exactly expresses the idea; but in others

it is inappropriate. The principal structures recognized among the ore bodies under consideration are:

A. The banded structure;

B. The brecciated or conglomeratic structure;

C. The granular structure;

D. The dense structure;

E. The crystallized structure.

A. By the banded structure is meant an arrangement of the different minerals which go to make up an ore body in separate parallel bands or sheets, whether these sheets are in flat or in cylindrical or spherical shapes. The banded structure is not very common in many lead or zinc deposits, and is generally confined to portions of veins or to the fillings or incrustations of cavities. Examples in Missouri are rare; smithsonite is sometimes found in this form. Incrustations in bands occur at Carinthia; banding characterizes veins in Cornwall, in the Erzgebirge, at Pontpean and the deposits of Laurium. It is also sometimes found in interbedded deposits, and sometimes it occurs in the smaller lenticular bodies as well as in those of cylidrical form. Instances of such are, however, rare.

B. The brecciated or conglomeratic structure is where the ore body consists of a mass of fragments of any size, firmly cemented or loosely held together. The fragments may be of the country rock, of the metalliferous mineral itself, or of any other material; the matrix may be clay, sand, quartz, calcite, or merely comminuted particles of the fragments. The fragments are generally angu'ar, but may be rounded or water-worn, or even lenticular or tabular. The metal-bearing minerals are generally diffused in the matrix, though they may constitute some of the larger fragments of the breccia. This structure is frequently found in tabular deposits, either in beds or veins, and sometimes such a brecciated vein may be in part of brecciated structure, and in part of banded structure. This structure is also observed in lenticular deposits. The most frequent occurrence of this structure is to be observed in what we have termed massive deposits. Familiar types of these are many of the deposits of Jasper and other counties in southwestern Missouri; also, many of the veins of central and southern Missouri belong to this class. In Europe, the deposits of Bleiberg, Shropshire, Gladbach, and many of the Erzgebirge exhibit this structure. An extreme case of conglomeratic structure are those surface bodies of ore so common in the Mississippi valley, in which the

early "clay diggings" were prosecuted. They sometimes consist partly of fragments of rock surrounded by clay enclosing lead or zinc ores, but often they consist almost entirely of clay, with masses of galena or dry bone scattered through it.

C. By granular structure is meant a firm or an incoherent aggregate of grains of pure ore, or of grains of a mixture of ore and rock and other minerals, or both. This structure characterizes ore bodies of almost every form, though it is perhaps most prevalent in stratified bodies. It is often difficult to separate this structure from the crystallized, as will appear from the definition of the latter given farther on; in fact, the two grade into each other. Examples of this class are the disseminated ores of southeastern Missouri; parts of the deposits of Carinthia, Przibram, Mechernich and Laurium.

D. The dense structure pertains to those bodies of ore of which the whole material between the wall rocks is homogeneous in composition and is not separable into fragments, grains or crystals. Perfect homogeneity perhaps never occurs, and instances of this class which approximate the definition are comparatively rare and characterize the smaller and relatively unimportant ore bodies. Examples of these are the solid bands or layers of galena found between limestone walls in Morgan, Miller, Franklin and Washington counties of Missouri; also in Wisconsin and Illinois.

E. By the crystallized structure is meant one in which the whole ore body is made up of a mass of interlocking crystals, consisting either all of the same mineral species, or several such species. Bodies consisting entirely of such aggregates of crystals are exceedingly rare; but we recognize as belonging to this class those bodies which are in very large part of this structure. As previously stated, however, it is often impossible to separate them from the granular. Some of the carbonate ores of Leadville might be included here, and also smithsonite and calamine deposits of Missouri and elsewhere. Another classification based on structure might be formed with reference to the condition of consolidation of the material. Some ore bodies are thoroughly indurated, through the action of percolating solutions, so that the parts are firmly cemented together; others are barely coherent and can be excavated with pick and shovel. In the indurated bodies the cementing material may be quartz in the form of an impure quartzite, may be calcite, barite or any other constituent of the body which has been deposited from solution.

7. *The Mode of Formation of the Ore Body.*—We have already, under a previous heading, considered the mode of formation of the metalliferous constituents. There are, however, other forces and conditions which are influential in the formation of ore deposits, and which are to be ranked among the causes producing them. A consideration of these is, therefore, necessary in order that the history of the ore bodies may be made complete. Accordingly, we may group these deposits with reference to their structural relations, as follows:

A. Bodies formed by the impregnation of the country rock without prior alteration or disturbance of the latter;

B. Bodies formed by the entire replacement of the country rock;

C. Bodies formed by the filling of cavities or interstitial spaces in the country rock, produced by chemical alterations or by disturbances;

D. Bodies formed by the action of differential weathering.

These groups are based not so much upon differences in the forces producing them as upon their structural and geologic relations; under them may be included all of the important deposits of lead and zinc ores.

A. As ore bodies formed by the impregnation of the country rocks we should class all deposits consisting of sedimentary or massive rocks with lead or zinc compounds diffused through them, whether this was by chemical or mechanical means; whether these compounds were deposited in *minute* cavities or crevices sufficiently abundant in the rock to make the whole rock essentially one body of ore, or whether they were deposited through metasomatic action. The disseminated ores of southeastern Missouri are familiar examples of this class, and, in Europe, at Mechernich, Carinthia, Vieille Montagne, Rammelsberg, Wiesloch, Laurium and Upper Silesia such are also found.

B. The formation of an ore body by the entire replacement of the country rock is plainly only an advanced stage of the impregnated condition, one in which little or none of the country rock remain mixed with the ore. Many large "chamber or cavern deposits" are doubtless to be included here, such as those at Leadville and perhaps those at Eureka. Some sheet deposits or veins may also have been formed in this way—the replacement following along a joint plane or fissure. The disseminated ores of Missouri sometimes approach this condition, and it is abundantly represented in the deposits of Carinthia, Vieille Montagne and Iserlohn in Europe.

C. Bodies formed by the filling of cavities may be subdivided into: (a) those of which the cavities have been formed by solution; (b) those formed by mechanical action.

Of the first class are at least some of the cave or chamber, pipe and chimney deposits, so frequent in limestone, examples of which are too numerous to need mention; also many crevice deposits, such as gash veins, occurring in limestone and other rocks, and abundant in the lead and zinc regions of the Mississippi valley. Further, to be included in this class, are those deposits which have been formed by the deposition of the metallic compounds in a mass of residuary products resulting from the partial decay of the country rock. If the indestructible portions of the rock are in sufficient quantity, are of proper form and of sufficient strength, the solution of the other portions will simply leave an open, honey-combed or cavernous rock for the reception of the metals; if they are in small quantity and are incoherent or fragile, they will collapse on the removal of the soluble parts, forming a more or less brecciated mass, in the interstices of which the metals and their accessories will be deposited, often cementing the whole into a compact mass. Many of the deposits of Jasper county are familiar and excellent examples of this class of ore bodies.

To the second class belong those deposits occupying fissures or brecciated zones produced by earth movements, such as fault crevices. Examples of these are most of the so-called "true fissure veins," such as those of Przibràm, Bleiberg, Cardiganshire and the silver lead mines of Mexico. In many cases, as intimated above, the cavity thus produced is not an empty space, but is partially filled with a mass of fragments of country rock and other materials, brought into the crevice by the faulting movement or other mechanical action. Between and around these fragments the metallic compounds are deposited, and so intimate is the mixture that the whole mass is included in the term ore body. This condition is very common, and is in fact the normal one with fault veins. Examples of such are common in Missouri, especially in the central and southeastern districts.

D. The most familiar examples of lead and zinc ore bodies formed by the concentrating action of differential weathering, are what are known as clay diggings in the Mississippi valley. These consist of lead or zinc compounds diffused through a body of loamy clay, or of clay mixed with varying proportions of undecomposed rock in the shape of fragments. They differ from the similarly constituted bodies pre-

viously described in that the ore existed originally in the rock in a more diffused state, and was not introduced into the clay or breccia after the decomposition of the rock.

8. The Nature of the Associated Substances.—Substances associated with lead and zinc compounds in ore bodies may be divided into two classes:

A. Fragments or particles of the rock, or its common residuary products;

B. Minerals originally deposited in the ore body.

A. The country rock constitutes part of many ore bodies of almost all classes. Where the ore body is an impregnated portion of the country rock, the latter is necessarily a part of it. Ore bodies formed in cavities, of whatever shapes or mode of origin, are liable to contain fragments of the country rock, as previously explained. A further subdivision, according to the nature of the rock, might be made, but the types are so obvious that this seems unnecessary.

B. A subdivision according to the nature of the associated minerals is more common and has more direct bearing upon the questions of the origin of the ores and their utilization. The most common mineral associates of lead and zinc ores are calcite, dolomite, barite and pyrite. Quartz in a separate or crystallized condition is found in some deposits, but it is, generally speaking, of exceptional occurrence; in the form of quartzite, more or less pure, it is, however, of abundant occurrence in some of the ore bodies. In intimate association with many galenas and other lead compounds is silver, giving rise to our argentiferous lead ores. A classification of lead and zinc deposits, according to the presence or absence of any of these minerals, may be made to suit special requirements. One according to the presence or absence of silver is common. A separation of those associated with barite has been suggested by Emmons [*82, p. 30*] as of genetic value; but as referred to later in this report, the significance attached to the association by him is not so great as was imagined.

9. *The Nature of the Enclosing Rocks.*—A classification based upon the nature of the enclosing rocks is of great value both for geologic as well as economic reasons. Lead and zinc ores are known to occur in massive or crystalline as well as in clastic rocks; they are found in granites and porphyries, in limestones and sandstones, in sands and clays. By far the greater number and the commercially most important of such bodies are found in or immediately associated with lime-

stones. Among these are included the large lead-producing deposits of Colorado, Nevada, Montana and Idaho; those of the Mississippi valley, those of Virginia, Pennsylvania, New Jersey and others. In Europe the great deposits of Upper Silesia, of Laurium, of Carthagena, of Santander, of Bleiberg, of Vieille Montagne, of the north of England, of Sardinia and many others are all in limestone, in whole or in part. This is an important fact, and one which has permitted the easy and extensive development of these deposits in many localities. Moreover, this fact of association with limestone is one which we consider of peculiar significance and importance in reaching the true theory of the genesis of these ores, as will appear later.

Instances of the association of lead and zinc ores with other rocks are abundantly described in the succeeding chapters IV and V; we will, therefore, not enumerate them here.

10. The Age of the Enclosing Rocks of the Geological Distribution.—Deposits of lead and zinc ores occur in rocks of all ages, from the Archean to the Tertiary. Those of most importance as sources of lead and zinc are, however, more abundant and more extensive in Paleozoic and Mesozoic rocks than in Algonkian or Archean. The series containing the largest and most noted deposits are the Silurian, Lower Carboniferous and Triassic. Examples of all are contained in the descriptions of the next two chapters. To illustrate these facts a little more prominently, however, we give the following list showing the distribution of the more prominent deposits:

Deposits in Archean or Pre-Paleozoic Rocks.—Ores of lead and zinc in large quantities in these rocks are not common in America. Those of Franklin furnace, New Jersey, are perhaps in Archean formations, and some of the deposits of the Kootenay district of Canada are in the Laurentian. In Europe are to be cited lodes of the Erzgebirge and northeastern Hungary; portions of the deposits of Les Malines, of Pontgibaud, of Correze and Aveyron, of Huelgoat and Poullaouen in France, and others in Corsica; also some of the less important ones of Sardinia and of Linares in Spain. The Ammeberg zinc deposits of Sweden are in Laurentian rocks and the lead deposits of Sala in Primitive magnesian limestones. The silver lead ores of Broken Hill in New South Wales are in Primitive gneiss and other rocks.

Deposits in Cambrian or Silurian Rocks.—In America the lead and zinc deposits of Wisconsin, Iowa and of central and southeastern

Missouri are in Lower Silurian limestones; those of Eureka, Nevada, are partly in the Cambrian and Silurian; those of Kootenay, Canada, are largely in Cambro Silurian; those of Wythe county, Virginia, are also in the Cambro-Silurian; those of Saucon Valley, Pennsylvania, in the Lower Silurian, and others in the Upper Silurian; probably the Franklin furnace ores of New Jersey are in Cambrian rocks. In Europe the Przibram lodes are in the Silurian; the lodes of Shropshire and adjacent counties of western England in the Cambro-Silurian. The deposits of Andreasburg in Germany, of Pontpean in France, and of Horcajo in Spain are in Silurian rocks, and some of those of Tomsk, Siberia. The more important bodies of Sardinia and of Linares, Spain, are principally in the Cambrian and Silurian. The deposits of Laurium, Greece, are also probably in Silurian rocks. In South America lodes of Bolivia are in Silurian rocks.

Deposits in Devonian rocks.—In America, only a few important lead and zinc deposits are assigned to this horizon. The most important are a portion of the ore bodies of Eureka, Nevada, and the silver-lead bearing lodes of Guanajato and others of central Mexico. In Europe such are comparatively common. Among these are included deposits described in Cornwall and Devonshire, England; in the Siebengebirge, at Eifel, Gladbach, Iserlohn, Holzappel and the Hartz mountains, especially at Rammelsberg, all in Germany. The lodes of Huelgoat and Poullaouen, in Brittany, penetrate Devonian as well as other rocks, and some of the deposits of Tomsk, Siberia, also belong to this formation.

Deposits in Carboniferous rocks.—Almost all lead and zinc ores of the Carboniferous are in the Lower Carboniferous series, which are generally limestones. To these belong the lead deposits of Leadville and Aspen, Colorado, and others of Utah. The zinc and lead ores of southwestern Missouri are also in these rocks. In Europe are the deposits of Derbyshire and the North of England counties, and those of Flintshire and Denbighshire; those of Bleiberg and Vieille Montagne in Belgium; in part those of Huelgoat and Poullaouen in France; those of Santander in Spain, and of Tomsk in Siberia, both also in part. At Carthagena in Spain are deposits in the Permian.

Deposits in Triassic rocks.—No great lead or zinc deposits in Triassic rocks have developed in America, though some of the lodes of central Mexico, carrying silver-lead ores, are in these rocks. In Europe, on the contrary, this horizon is a great source of supply. Prom-

inent among the Triassic ores, we may cite those of Carinthia in Austria, those of Upper Silesia in Prussia, of Mechernich in the Rhine provinces, and of Wiesloch in Baden, as well as other deposits in that duchy and in Wurtemberg.

Deposits in Jurassic rocks.—Here, likewise, there is a dearth of such ores in America, though lodes of Peru and Chili have been assigned to this formation. In Europe they are comparatively common. The more noteworthy of such are those of Santander in Spain (though the rocks may be Cretaceous), and those of Les Malines, Clairac and other localities in France.

Deposits in Cretaceous rocks.—The existence of these ores in Cretaceous rocks is somewhat doubtful; at least, at the more important localities. The deposits of Algiers are assigned to this formation; those of Laurium in Greece have also been placed there by some geologists, though the generally accepted opinion is that they are in the Silurian. Some, at least, of the ore bodies of Santander in Spain appear to be in Cretaceous rocks. In Peru, silver lodes traverse these rocks. In Mexico the Sierra Mojada ores have been placed at this horizon.

Deposits in Tertiary rocks.—The only noteworthy deposits of lead or zinc in Tertiary rocks are those of Tunis in Africa, which are placed in the Eocene.

OUTLINE MAP OF THE WORLD SHOWING THE LOCATION OF THE PRINCIPAL PRODUCING LEAD AND ZINC DEPOSITS SO FAR AS KNOWN.

CHAPTER IV.

LEAD AND ZINC DEPOSITS OF FOREIGN COUNTRIES.

EUROPE—AFRICA—ASIA—OCEANICA—SOUTH AMERICA—MEXICO—DOMINION OF CANADA.

In the preceding chapter we have considered the distribution of lead and zinc in nature, and their modes of occurrence. In this chapter we propose to consider their geographic distribution, and to accompany this by a brief description of the principal deposits in America and foreign countries.

Deposits containing lead ore, either alone or associated with other minerals of value, are known to exist and have been mined in all inhabited countries of the globe. They are found in North America, South America, Europe, Africa, Asia and Australia. The relative importance of the deposits of these countries, so far as developments show, may be judged of from the statistical tables and accompanying notes in chapter VI. As regards deposits in the comparatively unexplored regions of Africa and Asia, little is known, and it is impossible to arrive at estimates of values. The majority of these deposits are argentiferous, and of these, a considerable though smaller number are worked principally for the precious metals, the value of the lead product being comparatively small.

Zinc ores are of less wide distribution, but the deposits are frequently more extensive than those of lead. Ores of this metal have been worked in North America, Europe, Africa, Asia and Australia; but there are no zinc mines in South America, nor have workable deposits been discovered in that country which are generally known. Zinc, though often associated with argentiferous lead ores, is not in itself a carrier of precious metals, excepting in a few cases.

An exhibition of the general distribution of these ores throughout the world is given on the small map opposite this page. We will now proceed to describe the principal occurrences by countries, beginning with the foreign.

LEAD AND ZINC DEPOSITS OF EUROPE.(*)

Lead or zinc ores are known to occur and are mined in almost all countries of Europe. The large producers are Great Britain, France, Germany, Belgium, Sweden, Russia, Austria, Greece, Italy and Spain. The tables of production given in the tables of chapter VI show the relative importance of these countries as producers during recent years. Suffice it here to note that Spain is far ahead of all others in the output of lead ore, the yield being twice that of Germany, which ranks second. In the production of zinc ore Germany is far in the lead, and is succeeded by Italy with only about one-seventh of the former's production. Though these figures relate only to very recent years, they are indicative of more, and, with some variations, may be taken as a measure of past importance also. Thus the deposits of Spain have been large producers of lead from remote antiquity, and those of Germany have likewise been important sources of zinc supply from the beginning of the utilization of these ores. This fact and additional details of production will appear in the following descriptions, to which we will now pass without further generalization. These descriptions are of the countries above enumerated; they will be taken up in alphabetical order.

AUSTRIA.

Under the name Austria we mean all of what is known as the Austro-Hungarian monarchy, including Hungary, Galicia and Transylvania.

Both lead and zinc are mined in Austria in large quantities. From tables given in a following chapter it will be seen that the production during the past 12 years has averaged in the neighborhood of 15,000 tons of lead ore and 30,000 tons of zinc ore annually, though, in addi-

(*) In preparing the following descriptions of Europe and other foreign ore deposits, reference has been constantly made to Fuchs & DeLaunay's, Phillips', Von Groddeck's, Davies', Von Cotta's and Whitney's standard works on ore deposits. Hague's description, in Vol. IV of the Reports of the Paris Universal Exposition of 1878, have also been made use of. Much statistical information has been derived from the recently issued Vol. II of the Mineral Industry, and from Hunt's British Mining. In addition, numerous special works and papers referred to have been consulted, including the recent U. S. Consular report on Lead and Zinc Mining in Foreign Countries [*138*].

tion, very large quantities (90,000 tons from Hungary in 1891) of argentiferous galena, low in lead, are produced. Lead ore has been mined in this country probably over 1000 years, and perhaps as far back as the Roman period; the zinc deposits are of recent development, corresponding to the late general utilization of the ores of that metal.

The ores of the majority of deposits containing lead are argentiferous; but, on the other hand, those furnishing the greatest quantity of that metal, i. e., those of Carinthia, contain little or no silver. The provinces which at present may be ranked lead producers are Carinthia, Bohemia, Galicia, the Tyrol, Carniola, Hungary, Moravia and Styria; their rates of production during recent years are about in the order given. Of these the Carinthian, Styrian, Carniolan, Galicean and Tyrolese deposits also yield zinc.

Carinthian.—The Carinthian deposits have been described by Von Cotta and others, but they have been made classic by Posepny's researches and monograph [*173*]. They are of special interest in comparison with those of the Mississippi valley. According to Posepny they have been known for a long time, perhaps even as far back as the Romans, though positive evidence is not adducible. That they were in active development in the Middle Ages is, however, well established. In 1891 the province produced 9000 tons of lead ore [*91–vol. ii, p. 476*], and several thousand tons of zinc ore have been mined in some years. In 1892 the production was about 8300 tons of lead ore, yielding 5500 tons of lead. The crude ore of Bleiberg averages 8% of lead [*195-vol. ii, p. 402*].

Both the lead and zinc ores found here contain little or no silver. The principal mining centers are Bleiberg, Kreuth, Raibl, Windish-Bleiberg, Kappel, Miss and Schwarzenberg in southern Carinthia; these are distributed over a belt a few miles broad and about 100 miles long in an east to west direction.

The country rocks are principally Triassic, consisting of a complex formation of limestones and dolomites, with shale beds frequently intercalated, aggregating some 3000 ft. in thickness. These are overlain by dark, bituminous, clayey and marly shales. The lead ores are principally in the upper limestones; the zinc are in the dolomite. They dip to the south gently at Raibl and from 30° to 80° at Bleiberg; they are traversed by faults having throws of from 120 to 180 ft., disturbing both strata and ore bodies.

The ore bodies are of irregular forms, frequently pipe-shaped and without well-defined limits, and their axes seem to follow the intersections of stratification planes and fault fissures. Such bodies are in places as much as 1200 ft. long; they vary in diameter from 6 to 90 ft. They also traverse the limestone, often very irregularly in strings; are found in patches and in grains, and along some fissures they seem to impregnate the country rock. A peculiarity of these deposits is that they cease when an overlying shale bed is reached, but extend often along the contact as if this offered an obstruction to the passage of the solutions. They also often extend out along the stratification planes, resembling beds, or more exactly, a series of flat lenses, sometimes 20 ft. thick. The metalliferous minerals, galena, blende and pyrite, are often disposed in crusts, lining cavities, the central space being filled with dolomite. In Raibl the ores are most common along the N.-S. faults.

The principal ore is galena, some cerussite occurring in the upper workings. Smithsonite, the principal zinc ore (called calamine), is abundant at some places, but is not so generally distributed; it is not found in cavities like the galena, but is pseudomorphous after, or has replaced limestone; the silicate, calamine, is scarce. Some blende accompanies the galena. Pyrite is found only in small quantities. The principal gangue minerals are calcite, dolomite, feldspar, and a little quartz; barite is comparatively rare.

As to the origin of these deposits, various views have been held: they have been considered as deposited simultaneously with the enclosing strata; as originally distributed through the limestone and subseqently concentrated; and as deposited from solutions which penetrated the fissure [*225, p. 335*]. The last explanation is the one maintained by Posepny, he holding that the solutions have come from below and that the ores were deposited in spaces of dissolution. Stalactites of blende and galena are found, in evidence that these minerals were deposited directly from solution.

Bohemia.—The deposits of Bohemia contain both lead and zinc ores, and these are all argentiferous. Considerable quantities of lead are produced; but very little zinc.* The production of lead ore proper for 1891, Fuchs & DeLaunay place at 2700 tons. The deposits which call for notice here are those of Przibram, Mies, and those of Adamstadt and Rudolphstadt northeast of Budweis.

* Only 10 tons of zinc ore in 1891.

The Przibram ore deposits were worked at a very early date—just how early is not known—it is thought as early as the 9th century, and records extend back as far as 1330. They were reopened in 1527 and have been worked almost continuously since. According to Phillips [*168, p. 318*], they yielded from 1876 to 1881, 30,000 tons of lead, and in 1891, according to Fuchs & DeLaunay, 4800 tons. Several thousand men are employed, and the works extend to depths of over 3700 feet*. The country rocks are Silurian quartzites sandstones, and slates, bounded on the east by granites; the former are traversed by greenstone (or diorite) dikes, having a general N.—S. strike and a steep dip to the west, while these stratified rocks, though violently flexed and also faulted, dip generally N. 60° to 75° E. The ores occur in lodes or veins which follow the strike of the diorite dikes. They vary in thickness from an inch to 20 feet; they sometimes form contact deposits with the dikes and even send leaders into the latter. The dimensions and the distributions of the veins are very irregular. The metal-bearing minerals consist of pyrite, argentiferous blende and galena and other silver ores. The gangue minerals are spathic iron, calcite, dolomite, quartz and some barite. The galena occurs in the gangue in veins, bunches, lenses or disseminated in a quartzose matrix. The texture is generally granular; in one instance a banded arrangement was found. The crude lead ore contains about 20% of lead. Fuchs & DeLaunay characterize the filling as of the concretionary type. The ores seem equally abundant in the sandstone and quartzite, though less so in the slate; the influence of the country rock appears, however, to be purely mechanical. The decomposition of the ores extends to depths of 400 feet.

At Mies, we have, as country rocks, pre-Silurian clay shales with sandy layers. Through this run numerous parallel veins in a direction about S. 40, E. The principal one has a strike S. 30° E., and a dip of from 55° to 80° W. It varies in thickness, from a thread to 18 ft. The metalliferous minerals are principally galena and blende and their decomposition products; with these are pyrite and barite. The gangue is quartzose. Three mines here, in 1881, produced 3000 tons of argentiferous galena.

At Adamstadt and Rudolphstadt the country rocks are gneisses and schists, traversed by granite dikes. In these are lodes running in a

* The Franz Joseph shaft, when completed, will be 4294 feet deep [*195, vol. 2, p. 402*], and with the exception of the Tamarack shaft on Lake Superior, the deepest in the world.

N.–S. direction. They contain argentiferous galena and blende, in layers or distributed through the gangue. The latter consists, in some lodes, of decomposed quartzose dolomite; in others, of quartz, with horses of gneiss and granite. The veins vary in thickness, from 1 to 18 ft.

Galicia.—We will refer here to only one mining district, that of Kirlibaba in southern Galicia, described by Von Cotta. The deposits, here, containing argentiferous galena, have been worked for several hundred years. The country rock is principally mica, schist, containing a bed, about 300 ft. thick, of black, bituminous shale. In this shale are flat, irregularly distributed lenses of ore, which is parallel to the stratification, and are of sufficient size to be exploited separately; in addition, these shales are traversed by lodes, nearly parallel to the stratification, in which the minerals are disposed in bands. The lenses, it is suggested, were impregnated from these lodes. The ore bodies consist principally of argentiferous galena with spathic iron, blende, some pyrite and some quartz.

The Tyrol.—In the Tyrol are two localities worthy of notice, i. e. the lead and zinc deposits of Schneeberg and the copper and lead deposits of Klausen. In 1889 the province produced over 800 tons of argentiferous galena and nearly 3000 tons of blende.

The Schneeberg mines were worked for lead a long time ago; in 1486 as many as 1000 men were employed there. They seem to have been soon exhausted of their lead, and it was not until 1866 that they were reopened for the zinc blende. In 1880 it was estimated that the mine would produce about 7000 tons of blende and several hundred tons of lead ore. From 1877 to 1881 inclusive, the production was about 23,000 tons of blende. The country rock is a mica schist, generally striking E. and W. and dipping N. The deposits are in large lodes, 7 to 56 feet thick, which have been traced a distance of 1½ miles and proved to a depth of 3000 feet; they and the immediately associated schists generally strike N. E. and dip N. W. The ores consist of blende and galena, apparently banded, with a little pyrite and other minerals distributed in the veinstone.

The Klausen lead and copper deposits have also been worked for a long time. The country rock is here an argillaceous mica schist with layers of different composition. It is traversed by a broad mass of diorite associated with what is known as "fieldstone." The ore occurs in lodes traversing all of these rocks, the principal ones striking E.–W. and dipping 60° to 80° N.; they vary in thickness up to several

fathoms. The lode is galena bearing in the diorite, while, in the schist and fieldstone, it carries iron and copper pyrite and is generally leaner. The galena is somewhat argentiferous.

Hungary.—The principal lead-producing mines are in the vicinity of Schemnitz. The country rock consists of a "greenstone porphyry" surrounded by trachyte. Through this runs a group of seven parallel veins in an E.–W. direction, separated by intervals of 1000 to 2000 ft. The principal one extends three miles and is 12 to 22 ft. thick. Silver prevails with all in the western ends, while galena predominates in the eastern. The veinstone is feldspathic. The Biebergang is never less than 60 ft. in thickness. [*234, p. 168.*]

In the Banat, in the southeastern corner of Hungary, is an interesting series of contact deposits, which occur along a range of mountains 150 to 200 miles long. This range extends in a north to south direction, and is composed of igneous rocks, chiefly syenite, diorite and porphyry, probably of post-Cretaceous age. Von Cotta describes the deposits as occurring along the contacts between these rocks and associated limestone beds, and as having been deposited from solution in cavities formed by dynamic action and by solution. The forms of the deposits are, hence, very irregular. The contained metalliferous minerals are principally galena, blende and copper and iron pyrite with both gold and silver; the gangue is composed mostly of quartz and calcite. The ores are much decomposed near the surface.

Transylvania.—At Sinka, near Kronstadt, in southeastern Transylvania, is an interesting and peculiar series of argentiferous galena deposits. The country rock consists of mica schist with interbedded quartz strata, the whole traversed by porphyry dikes, generally of a brown, but sometimes of a green color. The ore deposits lie between five such dikes, which are only a few feet apart. They are not in the form of lodes or of beds or of impregnations, but are small concretionary-like masses distributed through the schist. The latter are decomposed adjacent to such bodies, and are sometimes impregnated with ore. They are somewhat like the lenses of Kirlibaba in Galicia; but no lodes, which might be considered sources of supply, traverse the rocks here. The ore is principally crystalline or granular galena with some cerussite, in cellular quartz or decomposed schist. Blende, copper and iron pyrite and their decomposition products are also found.

BELGIUM.

Both lead and zinc ores are mined in Belgium; but, though large quantities of lead ore have been produced in past years, the output during recent years has been reduced to only a few hundred tons per annum, while the annual production of zinc ore has been in the neighborhood of 25,000 tons. The lead ores mined, though containing small quantities of silver, are not to be classed as argentiferous; the zinc ores are principally the carbonate, smithsonite, and the silicate, calamine.

Mining of zinc ores in Belgium is believed to have been in progress as early as the 12th century* for use in the manufacture of brass; but the records do not go back farther than 1640, and it was not until 1806 that the first zinc furnace was constructed by the Abbe Dony [*94, p. 290*]. Lead mining was in progress during the early portion of this century, and doubtless before.

All the noteworthy lead and zinc deposits of Belgium are in the province of Liege, on the eastern edge of the kingdom. The principal of these are those of the Bleiberg lead mines and of the Vieille Montagne zinc mines, both near Moresnet. Other large deposits have, however, also been exploited near Verviers, Liege, Philippeville and other points, which we will briefly describe.

Bleiberg.—The deposit at this point has been by far the most productive of lead in the kingdom, and has also yielded large quantities of zinc. It is situated near Moresnet, close to the Prussian line. The exact date of the beginning of mining here we are unable to give. The productions since the first part of the century have, however, been large. From 1853 to 1878, Hague [*94, p. 286*] quotes the production as about 66,000 tons of lead and 33,000 tons of zinc, and Phillips [*168, p. 257*] expresses it as about 96,000 tons of zinc ore and 96,000 tons of lead ore. The lead ore, though containing a small quantity of silver, is not classed as argentiferous.

The country rock consists of Lower Carboniferous limestone and Coal Measure shales, sandstones and grits.

The ore body is a vein, normally about three feet thick, which traverses and may be traced across the outcrops of both of these formations—being proved for a distance of three miles in the Coal Meas-

* Ancient documents are reported to relate that calamine was mined near Moresnet as early as the beginning of the 7th century; but this seems to need confirmation [*209, p. 95*].

ure and one and a half miles in the Lower Carboniferous limestone. The vein is vertical or dips at an angle of 75° or 80° toward the east or west; its trend is N. 57° W. No faulting has occurred along this fissure and no eruptive rocks are associated with it. The vein shows evidence, however, of having been reopened at different times, and, accompanying this, there was sufficient movement to cause much secondary brecciation of the ore body.

The gangue consists principally of fragments of the country rock, more or less broken and decomposed; where there are shales there is thus much clayey material present. The metalliferous minerals have been deposited from solution in the cavities between these fragments, or in grains and strings through the clay; sometimes there is a banded arrangement of blende and galena in the larger cavities. The blende seems to have been formed before the galena. Calcite, silica and some pyrite occupy part of the space between the fragments, and are of later formation. The crude ore as mined contains about 18 per cent of metalliferous minerals.

At some places large cavities have been eroded out of the adjacent limestone, as much as 1600 ft. in length and 200 ft. across; these were lined with galena and blende, but through movements of the rocks these minerals have been almost entirely dislodged and are now buried in a great mass of breccia on the floor of the cavern.

At the junction of the Lower Carboniferous limestone and the Coal Measure rocks is an intercalated mass of galena which reaches to within about 50 ft. of the surface. It is without admixture of rock and has not been disturbed.

Very large operations have been conducted at these mines in past years; one of the great obstacles was the immense quantity of water with which the deposit is saturated. This is the only true vein which has been worked in Belgium, and is the only deposit there carrying lead and zinc ores in the Coal Measure rocks.

Vieille Montagne.—These mines, known also by the name of Altenberg and Kelmisberg, are situated near Moresnet. The earliest zinc mining in the kingdom was here. The ores are of zinc exclusively, no lead being mined. The production has been very large since 1846, when extensive mining was first begun. Up to 1856, 1,700,000 tons of crude ore had been excavated in open cuts. Since that time operations have been entirely under ground, and up to 1878 the total output

had reached over 200,000,000 tons, representing 1,600,000 tons of concentrated ore; since then the yields have continued large.

The ore body occupies a narrow syncline or basin of Carboniferous dolomite, the sides of the basin being composed of Devonian shales standing nearly vertically; the pitch of the trough is from 10° to 16°. The deposit is about 1400 ft. long in a N. E.–S. W. direction, 600 to 700 ft. wide, and about 200 ft. deep. The ore consists principally of smithsonite and calamine, and these have replaced the dolomite so completely that, in places, no traces of that rock are left. Intercalated strata and masses of dolomite are encountered, however, and one such divides the ore body of the basin into two parts, a north and a south one. The smithsonite and calamine are frequently in compact masses, but are generally in irregular forms and sometimes in a great number of layers, separated by clay. Willemite is also found in large masses, of 100 cub. yds. or more, promiscuously distributed. Smithsonite is most abundant in the upper portions, while calamine preponderates in the lower. Only very small quantities of blende or galena are found, and pyrite there is also little of.

Concerning the origin of these ores, authorities seem to agree in considering them derived from solutions issuing from depths, through the fractures with which the region is transversed [*91, vol. ii, p. 417*], the silicate and carbonate directly replacing the dolomite, and not resulting from the secondary alteration of blende. At Diegenbush, in a number of places, calamine is concentrated at the bottom of the deposit, under the blende.

Nouvelle Montagne.—At Verviers is a deposit of this name which Whitney [*234, p. 243*] describes as an immense pear-shaped body of zinc ore, forming an envelope around a dolomite interior. Deposits of lead ore occur here also.

Corfalie.—At this place, a few miles from Liege, a deposit containing calamine, galena and blende, in separate parts, occurs in the shape of flattened layers, 3 to 25 ft. thick, between Lower Carboniferous limestone and Coal Measure rocks; its attitude is nearly vertical. In 1851 the Corfalie company produced about 2000 tons of zinc and 550 tons of lead.

Welkenrodt.—This deposit is not far from Altenberg or Vieille Montagne, but is of an entirely different character. Von Groddeck describes it as a contact bed or mass [*226, p. 241*] lying between Carboniferous limestone and shale. Along the strike it is over 750 ft., and

it conforms to all the dips and flexures of the rocks. The lower portion of the ore body, next to the limestone, is either massive, drusy, layered or earthy calamine which passes into an ochery iron ore in the upper levels. The upper portion of the deposit, next to the shales of the hanging wall, is composed of black clay with nodules and seams of blende, galena and pyrite. The deposit dips steeply with the enclosing rocks.

Philippeville.—This is about the westmost locality of this series of Belgium zinc deposits. Ores occur here of the nature of contact beds, and consist of galena and blende in the form of inclusions in limestone. An impregnated stratum of dolomite, 5 to 6 ft. thick, is traceable here for two miles.

In general, regarding these Belgium deposits, it is to be noted that the zinc ores are confined to the limestones and are never in the sandstones or shales; that, even where crevices or fissures extend into the Coal Measure rocks, they are barren, with the one exception of the Bleiberg lode. The metallic contents of all these deposits are considered to have been supplied from depths and brought up through crevices or fault fissures.

GREAT BRITAIN.

Both lead and zinc ores are mined in Great Britain, principally in England and Wales. Many of the lead ores are argentiferous, but most of them contain a comparatively small amount of silver. By reference to the table of productions, in chapter VI, it will be seen that the kingdom ranks at present fourth among nations in the production of lead ore and ninth or tenth in the production of zinc ore. With lead, there has been an almost constant decline in production for the past 50 years—the output being less than half what it was in 1856.

The following table, extracted from volume II of the Mineral Industry [*p. 419*], gives the productions of lead of the most important districts during the last 20 years:

PRODUCTION OF LEAD IN THE UNITED KINGDOM.

(In long tons of 2240 lbs.)

Year.	North of England.	Derbyshire.	North Wales.	Mid-Wales, including Shropshire.	Isle of Man.	Scotland.	Ireland.	Elsewhere.	Total Long Tons.	Total Metric Tons.
1872	22.426	4,191	5,187	17,550	2,639	2,331	726	5.404	60,455	61,411
1873	20.359	3,116	3,712	16,990	3,131	2,125	885	3,915	54,235	55,127
1874	21,701	3,572	5,816	18,061	3,185	2,073	1,313	3,053	58,777	59,740
1875	22,131	2,090	4,169	18,799	3.158	3.078	1,387	2,619	57,435	58,376
1876	22,992	2,149	4,479	18,956	3,086	2,936	1,368	2.699	58,667	59,612
1877	26,115	3.300	4,897	18,164	3,342	2,105	1,241	2,238	61.403	62,410
1878	20.673	4,257	6.381	18,200	2,995	2,743	1.263	1,504	58,020	58,971
1879	17,245	4,079	5,629	16,788	3,267	2.770	911	944	51,635	52,481
1880	23,831	3,601	4,749	16,394	3,886	2,848	931	706	56.949	57,882
1881	18,754	2,875	4,490	14,249	4,183	2,839	636	557	48,586	49,383
1882	19,316	4,205	4,756	10,381	4.263	3,377	734	3,296	50,328	51,153
1883	11.274	2,638	3,755	12,279	4,546	3,613	358	722	39.189	39,821
1884	16.376	2,744	3,349	9,076	4,439	3,219	341	531	40,075	40,732
1885	17,144	3,407	2,580	5,970	5,094	3,243	88	161	37,687	38,405
1886	18,246	3,505	2,783	6,534	4,629	3,433	177	175	39.482	40,129
1887	17,223	3.244	3,182	6,317	4,864	2,821	230	9	37,890	38,511
1888	16,351	3,375	4,095	5,614	4,733	3,143	196	71	37,578	38,194
1889	13,740	3,866	4,600	5,321	4,753	3,163	160	....	35,604	36,187
1890	13,149	3,020	5,074	4,851	4,530	2,881	5	80	33,590	34,140
1891	11,531	3,157	4,909	4,434	4,926	3.198	7	33	32,205	32,733
1892	9.786	2,836	5,232	3,589	4,930	3,064	31	72	29,540	30,014
1893	....	....	....	....	....	....	....	....	....	....

This table is compiled from statistics in the British blue books, which make no distribution of the product for the years 1858–71, both inclusive. The column "North of England" includes the production of Northumberland, Cumberland, Westmoreland, Durham, and Yorkshire; "North Wales" includes Flintshire and Denbighshire; while Cardiganshire, Montgomeryshire, and the English county of Salop (Shropshire) are grouped under the caption "Mid-Wales." In all the English statistics the production of lead is estimated from the output of dressed mineral reported by the mines, the amount of metal obtainable by smelting being reckoned at 95% of the dry assay value of the mineral.

The working of the lead deposits was of a very early date, certainly as far back as soon after the Roman invasion (55 B. C.), and perhaps earlier. Zinc ores were mined as early as the 12th century, and possibly before, for the manufacture of brass, though the metal zinc was not known or extracted before the 18th century.

Deposits of these ores are found in the northern, central and south-eastern counties of England and in Cornwall and Wales. During recent years the production has been greatest from the counties of Durham, Northumberland and Cumberland, from Derbyshire, from Flintshire, from Cardiganshire and Shropshire. In Scotland, Lanarkshire and Dumfriesshire have been important producers, and Isle of Man yielded in 1891 more lead ore than any one county of England, Durham excepted. In past years Montgomeryshire, Denbighshire, Yorkshire, Cornwall and others have been large producers. These various deposits we will now describe briefly, somewhat in the order of their importance.

Durham, Northumberland, Cumberland, Westmoreland, Yorkshire.—The contiguous portions of these five northern counties constitute what is known as the North of England lead district. Here are themost important

lead deposits of the United kingdoms. They were operated as early as the Roman occupation, but records of mining do not extend back beyond the 13th century [*116, p. 148*]. Since then the deposits have been worked at intervals to a greater or less extent.

Both lead and zinc ores are mined here, the former slightly argentiferous, containing generally only a few ounces of silver to the ton, and the pure galena never over $\frac{1}{10}$ of one per cent [*54, p. 68*]. The average lead contents of the crude ore is about 8.5% [*195, vol. ii, p. 418*].

The productions of the early years of mining have not been recorded. Between the years 1845 and 1882, according to Hunt, the Durham and Northumberland mines produced from 15,000 to 26,000 tons of ore annually, 20,000 tons being about an average. Between 1878 and 1882, according to the same authority, Cumberland averaged about 1500 tons of zinc ore. Fuchs & DeLaunay place the lead ore production of Northumberland, in 1880, at 17,600 tons, of Yorkshire at 4700 tons, of Cumberland 2900 tons, and of Westmoreland 1700 tons; in 1891, Durham 8600 tons, Northumberland 3600 tons, Cumberland 2900 tons, Yorkshire 1700 tons, Westmoreland 1600 tons. The whole district produced in 1880, 26,700 tons of lead; in 1891, 12,900 tons; in 1892, 11,000 tons [*195, vol. ii, p. 419*].

The country rock is Lower Carboniferous limestone, 2800 ft. thick as exposed along the Pennine chain of mountains, following very nearly the axis of a great anticline. The formation is made up of thick beds of limestone, in part magnesian, alternating with sandstones and shales; it is overlain by the Millstone grit and Coal Measures. The limestone beds vary from 15 to 64 ft. in thickness, and the ores are principally associated with these—the richness and thickness of the veins varying with the rock. These rocks are traversed by a vast number of lodes running in different directions. The so-called 'rake veins" are diagonally across the strata, in a N. W.–S. E. direction, and these are the most profitable; they are nearly vertical as a rule, but have an irregular zig zag section, like a flight of stairs, flat stretches alternating with vertical. They are usually 1 to 4 ft. thick, but range up to 17 ft. Deposits of ore following the stratification are known as "flats," and are often very productive, and sometimes lead into large caverns encrusted with galena and other minerals. Pipe veins are also recognized. The limestone is generally much decomposed along the lode. The veins, according to Phillips, are usually along fault fissures, the throw varying from a few inches to 300 ft. [*121, p. 185.*] Where different rocks

are brought opposite each other by such faulting, lead ore is not commonly found. A layer of trap, 60 and more feet thick, separates the formation into two parts, and, at Alston Moor, this trap constitutes the base of the metalliferous zone. The intrusion of this trap, Phillips states, appears to have been posterior to the formation of the east and west veins. Ores are only present in this formation when accompanied by this trap. The metalliferous minerals are principally galena and blende, with pyrite, calcite, barite, feldspar and quartz in the gangue, and sometimes brown iron ore and spathic ore.

The source of these ores, Wallace [*227, p. 242*] suggested might be the very limestone and sandstone in which they occur, through the leaching, by circulating waters, of small quantities of diffused minerals. Posepny [*171*] considers the great length of these veins evidence of the existence of deep subterranean channels, through which solutions from depths were conducted.

Derbyshire.—Derbyshire is another county of very ancient mining, evidence of work in Roman times being found here also. Prior to the latter part of the 13th century, probably the only lead mines worked to any considerable extent by the English were here. The production of lead ore in 1876 is given as 2500 tons, and in 1891 as about 5000 tons. In 1892, the production of lead was 3200 tons. Between 1878 and 1882 the annual zinc production did not exceed 50 tons. The lead ore here is slightly argentiferous, like that of Cumberland and adjacent counties just described.

The country rocks are the limestones and associated strata of the Lower Carboniferous, like those of the preceding counties; they are here, however, traversed by a greater number of greenstone dikes ("toadstones") and are generally much faulted. The greenstones are probably both contemporaneous with, and also later injected into, the limestone beds. They are composed of augite, plagioclase, oxide of iron and sometimes olivine and apatite; they are sometimes compact and sometimes amygdaloidal or scoriaceous. These dikes vary in thickness from 30 to 100 ft. The ores occur in veins of the same character as those of Durham and Cumberland, and they are similarly classified. They are closely associated with the greenstones, but, in the great majority of cases, do not penetrate these, though they sometimes enter them, but at the same time become broken up and diffused. Few of the crevices in the extension of these veins in the overlying slates and Millstone grit are metalliferous. Most of the deposits are in one zone

of limestone. The ores and associated minerals are the same as in the counties described. According to Fuchs & DeLaunay the veins become universally impoverished with depths—the copper and zinc constituents disappearing before the lead. Workings extend to depths of 600 and 800 ft.

Shropshire.—In the southwestern part of this county are deposits containing both lead and zinc ores, the former at times somewhat argentiferous. These were opened as early as the Roman occupation, were worked in the 12th and 13th centuries, and continue to yield considerable quantities of ore to this day. In 1876 the production of lead ore is given by Davies [*58 p 201*] as about 9000 tons; according to Fuchs and DeLaunay it was 2000 tons in 1891. The zinc ore output between 1878 and 1882, according to Hunt, averaged about 600 tons annually.

The mining area is a small strip, about four miles wide and seven miles long, extending across a belt of strongly folded Cambro-Silurian beds. The ore-bearing strata aggregate about 5000 feet in thickness, and consist of dark slaty beds, sandstones and shales, traversed by greenstones and feldspathic dikes, and having interbedded traps and porphyries. The deposits, which are generally along the anticlines, are in the form of lodes, which traverse the strataprincipally in a W. N. W.—E. S. E. direction; these are filled with fragments of the country rocks cemented by barite, calcite, quartz and feldspar.

In this matrix galena and blende are found, generally in irregular strings, which lead into nests of ore—the metalliferous portion of the ore body thus constituting pipes or runs in the lode. The most productive portions are where the lode traverses hard rock. The lead ores from only two mines, says Davies, have yielded silver.

Montgomeryshire.—This county was probably also the scene of Roman mining, and operations were active here 150 years ago and have continued up to recent years. In 1876 the production of lead ore was over 10,000 tons, and between 1878 and 1882 nearly 2000 tons of zinc ore were produced annually. The lead ore is more argentiferous than that of Shropshire.

The country rocks and forms of occurrence of the ore are similar to those of Shropshire, and the rocks are similarly distributed. The lodes vary greatly in thickness, from a mere thread to 12 feet. The metalliferous ores are principally galena and blende, and with these are associated barite, witherite, calcite and quartz. In the Van district,

where the most noted mines occur, is a monster lode, 12 to 80 feet thick, filled with country rock and clay, traversed by veins of calcite, quartz and barite. The metals are distributed throughout in small bunches, cemented by strings, and these are sometimes more abundant near the walls than in the interior.

Carnarvonshire.—Here are lodes traversing tilted Cambro-Silurian slates and grits and feldspathic rocks. They have an E.—W. direction, and are generally 2 to 4 ft. thick, though one is as much as 30 ft. in places. They contain galena, with quartz and calcite, the first argentiferous.

Cardiganshire.—Mining in this county is apparently of very ancient date. Davies places it probably as far back as the time of the ancient Britons, and pretty certain in the Roman period. In the time of Queen Elizabeth the mines were worked, and from then at intervals to the present. Both lead and zinc ores are produced, the former often rich in silver. In 1845 about 6500 tons of lead ore were mined, in 1882 4500 tons, and between these dates the average annual production was close on 7000 tons. In 1891 over 2400 tons were mined. Between 1878 and 1882 the production of zinc ore ranged from about 600 to 4000 tons annually. The ores are found along several belts extending in a N. E.–S. W. direction, from Montgomeryshire to the sea, and corresponding to the anticlinal axes of Cambro-Silurian strata. The lodes have generally an ENE.–WSW. direction, and dip S. 60° to 80°. The gangue is principally quartz and fragments of country rock, through which the galena and blende are distributed in ribs and masses and in a net-work of veins, and also intimately mixed with the gangue; the minerals are not arranged systematically. Some copper and iron pyrite, barite and calcite occur with the ores, but no fluorspar. Near the surface some carbonate and phosphate of lead are found with a little calamine. Most of the ore is found where the lodes traverse the harder slates. An enrichment also occurs at the intersection of the lodes. No igneous rocks traverse the formation here.

Flintshire and Denbighshire.—Mining in these counties reaches back also probably to the Roman period, and the productions at the present time of both lead and zinc ores are large. The lead ores are argentiferous. In 1876 the two counties yielded over 6300 tons of lead ore, and in 1891, 7200 tons. Between 1878 and 1882 the yield of zinc ores ranged from 6000 to over 11,000 tons annually. In 1892 the Minera and New Minera mines at Wrexham produced 7200 tons of zinc ore

and only 1600 tons of lead ore. The most important mine of Denbighshire at present is the Holkyn at Holywell, producing about 3400 tons lead and 900 tons zinc ore per annum.

The country rocks belong to the Lower Carboniferous limestone series, overlain by the Millstone grit and the Coal Measures. The limestones are traversed by parallel lodes, coursing principally in an E.—W. direction across the formations and the trend of the belt. They are productive in the Millstone grit, but are represented by barren fault fissures in the Coal Measures. The shapes and associations of the ore bodies resemble those of Derbyshire. They are normally crevice-filling veins; but in the limestones they occur in flats and pipes and large caverns, and the adjacent rock is open and decomposed. Very pure galena occurs here and also large quantities of cerussite; zinc is mostly in the form of blende. The gangue is largely clay and the associated minerals are calcite, a granular quartz, and barite. No igneous rocks are associated with these deposits.

Cornwall.—Large quantities of zinc ore and of argentiferous lead ore have been mined in Cornwall. In 1845 over 11,000 tons of lead ore were produced. From this, the output, with some fluctuations, declined steadily to 1882, when only 700 tons were produced. No production is given for the county by Fuchs & DeLaunay in 1891. During the five years, 1878 to 1882, about 28,000 tons of zinc ore were mined. The principal mines are north of Truro in the western part of the county, and near Liskeard in the eastern part.

North of Truro the East Huel Rose and West Chiverton were the principal mines. The latter worked a lode running E.-W., dipping 20° S., 6 ft. wide and filled with clay, quartz and calcite as a gangue, in which galena and blende occurred both in layers and disseminated. The country rocks are clay slates, of probably Devonian age. Elvan dikes traverse this lode, and the ore is more abundant and richer in silver in their vicinity.

Near Liskeard are several different districts in which are the Herodsfoot and other mines. The country rocks are Devonian slates with conformable sheets of elvan, which is a feldspathic and hornblendic igneous rock, containing often spheroidal masses of quartz and galena arranged in concentric layers. The productive lodes run in a nearly N.-S. direction, and dip from 70° to 80° E.; they vary in thickness from a few inches to 4 ft. Quartz is the principal gangue, often

granular and sometimes banded, containing galena and blende. Carbonate and phosphate of lead occur near the surface. Pyrite is also present.

Devonshire.—The lead mines of this county were worked by the Romans, and were of great importance in the past, being extensively worked in the 13th and 15th centuries, and also down to the last quarter of this century. In 1876, however, only about 500 tons of lead ore were produced, and in 1831 but 10 tons; for 1891 no production is given. The principal deposits were in the southern part of the county, near Beer Alston, and in the northern part, near Combe Martin.

Near Beer Alston were lodes traversing Devonian, calcareous slates in which galena was disseminated in lumps through a matrix composed largely of fluor spar. The galena was very rich in silver.

Near Combe Martin the lode traverses a Devonian slate close to its contact with limestone; the gangue is of quartz and spathic iron, in which the galena occurs in courses and masses, principally on the lower side of the lode.

In Somersetshire, just north of Devon, lead and zinc ores are found in the Mendip hills. They occur in veins in the Lower Carboniferous limestones, and disseminated and in veinlets in a dolomite conglomerate. The veins are 1 in. to 3 ft. thick, and run in all directions; they contain galena, calamine, calcite, barite and quartz. Some little work is still done here on the old slag heaps.

Scotland.—In the southern part of Scotland, in Dumfriesshire, Lanarkshire and Argyleshire, are a number of lead deposits, some of considerable importance. Records of mining extend back several hundred years. Both lead and zinc are produced, but principally the former, and these are argentiferous. In 1845 the lead mines of Scotland yielded 1200 tons of lead ore; from this the output rose to nearly 5000 tons in 1882. In 1891, 4500 tons were produced. During the five years, 1878 to 1882, nearly 9000 tons of zinc ore were mined.

The mines at Leadhills in Lanarkshire and at Wenlock Head in Dumfriesshire are in Silurian rocks; the ores occur in lodes 4 to 14 ft. thick, and consist of argentiferous galena in fluor spar. At Strontian in Argyleshire, lead veins occur in granite.

Ire'and.—Lead and zinc ores occur and are mined in Ireland, principally in county Wicklow; but, also, in county Down. In 1845 the production of lead ore was 2200 tons, from which it rose to about 5000 tons in 1852; after this it declined, with fluctuations, to about 1100 tons

in 1882. During the three years, 1878 to 18~0, 360 tons of zinc ore were produced. The lead ore was highly argentiferous.

In Wicklow the ores are found in lodes, in Lower Silurian slates traversed by granite, porphyry and greenstone. The Luganure vein, which is one of the most important, is in granite, and dips 65° W. Galena occurs in layers or disseminated masses, associated with blende and copper pyrite. At Glendalough is an E.–W. lode, traversing granite and slate; the gangue is principally quartz, in which are cavities filled with clay, ocher and cerussite; argentiferous galena is also found in the lode, associated with copper pyrite, iron pyrite, some blende, barite and carbonate of iron. The production of these two mines, from 1870 to 1881 inclusive, was about 18,000 tons of argentiferous lead ore. At Glenmalure is a similar vein dipping 80°, 12 to 20 feet thick, from which 400 tons of lead ore have been produced annually.

At the Shulle silver mines a deposit in a fault fissure is described, containing argentiferous lead ore, copper pyrite, blende and calamine. It varies in thickness from a few feet to 20 feet and more. Closely adjoining is a large surface deposit of calamine, 10 to 60 feet thick, which seems to be a mass interbedded between limestone and dolomite, dipping north with the strata 20° to 30°.

Isle of Man.—The Isle of Man was the scene of very early mining —how early, is not recorded, but operations were undoubtedly in progress in the first part of the 15th century. During recent years large quantities of both lead and zinc ores have been produced, the former argentiferous. In 1845 the lead ore production was 2500 tons, and from that time it increased almost steadily to 6000 tons in 1882. In 1891 it was 7500 tons. From 1878 to 1882 the yield of zinc ore was 45,000 tons.

The ore deposits are similar in form and association to those of Carnarvanshire already described. The principal mines are the Foxdale and Laxey. At the former are lodes running 8° S. of E. The main lode is worked for a distance of four miles; counter-veins are found in the granite in the deeper workings. The lode ranges up to 40 ft. in thickness. The Laxey lode courses 9° E. of N., though Lower Silurian slates. Large amounts of blende are associated with the lead ores.

In the Orkney islands lead mines are also reported.

THE GERMAN EMPIRE.

The zinc ore production of Germany during the past ten years has varied from over one-half to nearly three-fourths of the production of

all Europe, or has averaged about 800,000 tons annually.* Of lead ore the output has been more moderate, though still large, averaging about 200,000 tons, or about one-fifth of all Europe's production. Almost all of this lead ore is argentiferous.

The following tables, from volume II of the Mineral Industry, give the productions of the principal districts during late years:

PRODUCTION OF LEAD ORE IN GERMANY.

(In metric tons; values in thousands of dollars, converted from marks at the rate of $1—4 marks.)

Year.	Silesia.		Harz Mountains.		Rhineland.		Total.	
	Amount.	Value.	Amount.	Value.	Amount.	Value.	Amount.	Value.
1872	13,905	$688	20,725	$952	41,969	$1,443	94,037	$3,758
1873	13,709	749	23,472	1,054	46,968	1,829	101,270	4,435
1874	16,287	990	20,708	892	47,839	1,771	104,088	4,569
1875	16,428	1,091	25,950	1,151	48,629	1,817	113,808	5,260
1876	17,844	946	28,880	1,082	50,470	1,915	120,603	5,097
1877	18,198	938	34,135	1,041	64,283	2,435	147,012	5,681
1878	17,390	739	33,435	995	67,078	2,366	152,843	5,266
1879	16,187	497	36,824	1,013	61,983	1,881	149,055	4,461
1880	17,766	643	41,344	958	61,352	1,903	159,726	4,780
1881	21,084	773	42,787	994	65,952	1,976	164,771	4,810
1882	24,256	876	45,812	998	70,811	2,123	177,656	5,155
1883	24,821	826	45,118	870	63,826	1,779	169,754	4,523
1884	25,860	773	42,977	770	56,670	1,437	162,772	3,935
1885	26,319	762	43,626	729	55,761	1,415	157,869	3,773
1886	29,316	912	46,425	768	53,102	1,471	158,505	3,980
1887	28,697	892	44,638	748	57,040	1,564	157,570	3,981
1888	29,223	838	43,310	747	59,147	1,741	161,777	4,171
1889	32,116	915	45,888	737	61,230	1,862	169,569	4,432
1890	32,504	926	47,787	766	60,083	1,851	168,234	4,524
1891	27,616	743	46,347	695	57,550	1,798	159,215	4,164
1892	27,878	661	48,032	528	56,720	1,570	163,372	3,672
1893	....	....	....	....	....	....	....	....

PRODUCTION OF LEAD IN GERMANY.

(In metric tons.)

Year.	Westphalia. Rhineland.	Nassau.	Harz.	Upper Silesia.	Saxony.	**Total.**
1880	47,882	8,464	10,159	13,596	6,107	**89,066**
1881	49,156	8,493	9,852	14,279	4,494	**90,340**
1882	52,165	8,979	11,026	15,793	5,990	**96,137**
1883	50,972	8,414	10,348	16,269	5,742	**94,965**
1884	51,998	9,373	10,809	18,173	5,923	**98,748**
1885	49,517	8,509	12,099	20,169	4,525	**96,488**
1886	45,819	a9,000	a12,500	22,870	4,780	**95,621**
1887	45,946	9,866	13,264	24,582	4,573	**98,478**
1888	47,360	11,562	13,723	22,133	5,783	**100,652**
1889	49,045	11,402	12,942	21,081	6,572	**103,740**
1890	47,876	12,240	13,941	21,673	6,583	**104,958**
1891	43,745	13,455	13,564	20,010	5,731	**98,114**
1892	45,084	14,113	13,054	20,158	7,162	**100,710**
1893	....	....	....	....	....	....

The figures for Rhineland and Westphalia in the above table are from the reports of the ***Verein für die*** *Berg- und Hüttenmännischen Interessen im Aachener Industrie-Bezirk*, and those for Upper **Silesia are from** the *Oberschlesische Berg- und Hüttenmännische Verein*. The Saxon figures are from the ***Jährbüche für das*** *Hüttenwesen im Königreich Sachsen*, and include the sales of lead and all lead **products. Litharge**, calculated at 80%, is also included in the Silesian figures. The latter do not, however, include **a few hundred** tons of lead won annually as a by-product at the zinc works. The totals are from the official **statistics of the** German Empire as calculated in the table on the second page of this article. The figures **marked (a) are** estimated.

* The great bulk of this ore is a low grade smithsonite and calamine, yielding not **more than 20 per**

PRODUCTION OF ZINC ORE IN GERMANY.

(In metric tons. Values in thousands of dollars converted from marks. 4 marks = $1.)

Year.	Silesia.		Rhineland.		Westphalia.		All Germany.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
1872......	337,601	$1,374	28,221	$322	31,124	$208	419,543	$2,154
1873......	366,426	2,231	27,952	355	32,827	252	444,950	3,116
1874......	367,476	1,869	30,699	391	27,303	197	451,222	2,777
1875......	377,939	2,157	37,615	486	29,013	218	467,953	3,171
1876......	449,374	2,244	36,305	476	25,123	218	533,559	3,252
1877......	477,919	1,775	43,868	480	29,798	233	577,312	2,785
1878......	505,042	2,014	39,285	372	31,293	234	597,193	2,856
1879......	500,763	1,307	42,148	307	28,000	214	589,546	2,013
1880......	530,994	2,023	51,166	455	31,202	261	632,896	2,983
1881......	553,487	1,537	56,428	435	29,536	216	659,531	2,399
1882......	580,207	1,898	50,837	532	40,480	300	694,711	2,978
1883......	560,684	1,173	53,569	532	41,802	281	677,794	2,223
1884......	515,317	963	57,604	526	39,161	258	632,040	1,955
1885......	554,297	968	63,735	463	41,781	271	680,654	1,912
1886......	578,856	887	67,260	571	39,133	259	705,177	1,931
1887......	768,429	1,386	68,601	582	40,969	277	900,712	2,506
1888......	540,384	2,173	64,857	614	38,192	315	667,761	3,437
1889......	582,149	3,077	64,549	610	38,315	297	708,829	4,423
1890......	635,538	4,318	59,743	620	38,849	342	759,437	5,854
1891......	666,615	4,589	61,707	700	38,507	336	793,544	6,239
1892......	661,369	3,633	69,260	777	42,575	380	800,237	5,305
1893......	....	......	....	......	....	......	....	......

The ores from which the lead of the first table is produced are argely domestic, but are also imported from Austria, Belgium, Spain and other countries.

As in the adjoining countries of Austria and Belgium, mining within the limits of the German empire dates back many hundreds of years. In Rhenish Prussia, the smithsonite deposits were doubtless worked as early as those of Belgium, or in the 12th century for a certainty, and perhaps much earlier. At Wiesloch, in Baden, mines were worked in the 11th century; about Holzappel in the 12th.

The great zinc-producing region of Germany has been Upper Silesia, probably over three-fourths of the output having come from there. Next in order of importance are the Rhine provinces, Westphalia and Nassau. In lead production the Rhine provinces rank first, and after these come the Harz, Silesia, Saxony and Nassau.

Upper Silesia.—The famous zinc and lead deposits of this province are in its extreme southwestern portion, about Beuthen and Tarnowitz on the Polish border, in which latter country are also important mines. Lead as well as zinc ores occur here, but the former, which are are argentiferous, are in quite subordinate quantities. In all the mines of this district nearly 10,000 people have been employed during recent years. Lead mining was commenced here as early as the 12th century, and has been actively pursued during various periods since.

In 1552 over 7000 tons of lead were produced, in 1860 over 23,000 tons of lead ore, and in 1890 over 36,000 tons. Zinc ore was mined for the manufacture of brass in the 16th century; in 1792 over 1000 tons were produced. During the past few years some of the largest deposits have become nearly exhausted, and the production threatens to be reduced.

The following table gives the recent productions in great detail:

PRODUCTION OF ZINC AND LEAD ORE AND OF ZINC IN UPPER SILESIA.*
(In metric tons.)

Year.	Blende.	Calamine.	Total Zinc Ore.	Iron † Pyrites	Iron Ore.†	Lead Ore.	Zinc.	Zinc Sheets.	Zinc-White, etc.	Total.	Average Value per Ton of Zinc.
1861..	....	283,487	....	....	....	3,149	42,033	8,406	968	51,407	312
1862..	....	279,722	....	....	....	4,855	41,700	9,165	969	51,834	315
1863..	....	234,744	....	....	....	8,580	40,600	8,975	1,180	50,755	314
1864..	....	237,540	....	....	....	10,973	38,573	7,430	833	46,836	396
1865..	....	268,384	....	....	....	6,164	35,430	9,164	834	45,428	382
1866..	....	286,166	....	....	....	8,767	34,864	6,016	756	41,636	392
1867..	....	299,424	....	....	....	9,912	36,832	5,084	753	42,669	389
1868	....	290,362	....	....	....	11,860	37,631	8,084	719	46,434	378
1869..	....	324,669	....	....	....	13,123	37,917	11,762	280	49,959	382
1870..	....	310,909	....	....	....	16,010	36,516	10,047	346	46,909	349
1871..	....	269,626	....	....	....	14,339	32,091	13,452	488	46,031	357
1872..	....	332,066	....	128	15,507	14,610	33,065	13,854	386	47,305	408
1873..	....	367,582	....	355	8,686	14,589	36,382	13,092	692	50,166	478
1874..	....	361,747	....	1,101	6,746	16,866	41,181	16,121	842	58,144	423
1875..	....	377,567	....	1,713	8,598	17,871	42,855	15,746	937	59,538	454
1876..	....	442,837	....	2,253	6,055	19,105	49,376	18,612	795	68,783	431
1877..	....	472,422	....	2,074	10,546	19,370	57,478	18,699	925	77,102	368
1878..	57,782	432,678	490,460	2,891	15,556	20,273	59,789	19,031	931	79,751	322
1879..	62,291	430,041	492,332	3,213	15,908	19,064	63,564	19,805	893	84,262	300
1880..	81,547	445,407	526,954	4,028	19,608	17,760	66,044	16,732	916	83,692	340
1881..	99,809	444,281	544,090	2,578	28,795	21,078	67,771	24,517	1,008	93,296	304
1882..	120,291	459,056	579,347	2,840	35,867	24,230	69,992	20,682	3,716	94,390	316
1883..	122,799	505,185	627,984	2,131	26,178	24,810	71,468	24,846	3,818	100,132	283
1884	143,344	445,985	589,329	1,457	46,858	25,861	76,897	25,474	3,778	106,109	267
1885	159,276	447,330	606,606	1,585	54,780	26,313	78,477	25,347	3,707	107,531	253
1886	a172,780	371,935	544,715	2,083	53,112	29,286	82,712	25,066	3,746	111,524	256
1887..	a193,826	358,788	552,614	2,930	57,559	28,508	82,640	29,141	3,128	114,909	275
1888.	212,264	319,316	531,580	1,583	33,344	29,601	84,777	25,821	2,811	113,409	324
1889..	246,955	325,705	572,660	1,971	20,268	32,146	86,947	32,562	922	120,4[illegible]	359
1890..	a261,921	343,495	605,416	1,949	11,287	32,498	88,699	32,547	896	122,142	441
1891	a271,277	324,331	595,608	2,076	8,088	28,716	88,420	37,669	1,151	127,240	443
1892..	....	....	b659,847	2,520	9,371	29,049	88,175	33,266	895	122,336	388
1893..	290,087	c344,429	634,506	2,104	7,083	30,825	91,659	35,187	207	127,053	....

* For the years 1861–91, inclusive, from *Die Bergwerks- und Hüttenverwaltungen des Oberschlesischen Industriebezirks*, Kattowitz, 1892. For 1892 and 1893 from *Statistik des Oberschlesischen Berg- und Hüttenmännischen Vereins.*

† Products of the zinc-lead mines.

(*a*) Besides which there were recovered from the old dumps of the Scharley mines 26,555 tons in 1886, 252,747 tons in 1887, 25,000 tons in 1890, and 67,500 tons in 1891.

(*c*) Includes 31,362 tons from old dumps.

The rocks in which the deposits occur are Triassic limestones and dolomites, more or less flexed. The ores, especially those of zinc, are found generally in depressions under lenticular masses of dolomite, and are especially abundant near the margin or lips of these lenses; they also occur in the depressions in the limestone floor under beds of clay and limonite. The lead ores are more frequently in the mass of the dolomite. Pipes and irregular cavities filled with ore are also found. The deposits are worked extensively by open cuts. The principal zinc ore is smithsonite, though calamine occurs also, generally at lower levels, while blende is found at the

bottom of the deposits. A considerable amount of cadmium is sometimes combined with the smithsonite. These ores frequently occur in layers alternating with clay. The lead ore is principally galena, and occurs associated with the zinc compounds, and also locally impregnating the dolomite. In the vicinity of the deposits the limestone is more or less decomposed, presenting irregular and bleached and softened surfaces. The zinc ores are low grade, yielding on an average only about 20 per cent of metal.

These deposits were considered by Krug von Nidda to have been derived from springs containing the metals in solution, from which, by a reducing action of the wall rocks, the minerals were precipitated and replaced the limestones. Runge, according to Phillips, is inclined to consider them the result of solution and concentration of finely divided zinc ores, originally disseminated in the country rock. Fuchs & DeLaunay describe them as sedimentary beds contemporaneously impregnated with the sulphide ores, from which the carbonates and silicates have been derived and concentrated by secondary changes.

The Rhine Provinces.—The mines of the Rhine provinces are within a district about 100 miles long, from east to west, and some 50 miles broad, north and south, all south of the latitude of Cologne and traversed about midway by the Rhine. Both lead and zinc ores are mined, the former being argentiferous. The total production of the provinces in 1881 was 62,700 tons of zinc ore, and 81,300 tons of lead ore; in 1890 the production of lead ore was 66,700 tons.

Mechernich near Commern is one of the most interesting deposits of the region. It is situated about 30 miles southwest of Cologne. Near by, lead mines were wrought as early as the Roman period. In 1893 the Mechernich company produced 39,000 tons of lead ore, which yielded over 22,000 tons of metal. The country rock is a variegated Lower Triassic sandstone, with intercalated conglomerate beds, aggregating two to three hundred feet in thickness. The basal member is a coarse conglomerate, composed of boulders of Devonian rocks, with ore immediately adjacent. These rocks are traversed by numerous faults, along which there have been displacements of from 125 to 140 ft. Through this sandstone the ore occurs in nodules, from the size of a pin's head to that of an apple, somewhat irregularly distributed. These nodules are composed in part of quartz grains cemented by galena (sometimes by cerussite), and in part, according to Posepny, of aggregates of galena crystals. He also observes that they are some-

times quite dense along the fault fissures, which also contain threads of the ore at times. The sandstone is friable, and the ore is most abundant in the white portions. At Bleiberg, these nodules constitute from 4 per cent to 10 per cent of the mass of the rock, and the lead contents of the rock at Mechernich varies from .05 per cent to 5 per cent of lead, and the silver from .03 ozs. to 18 ozs. to the ton. Some pyrite is found associated with the galena. The origin of these ores was traced by C. Haber, a good many years ago, to the traversing fissures, from which, he argued, impregnating solutions had flowed. Posepny has recently expressed himself in favor of the same view, and has suggested that some particles of organic matter originally formed nucleus of each nodule and induced the deposition of the galena. Von Groddeck, however, has advanced the opinion that a later infiltration of the ores is very improbable, and that the conditions point to their simultaneous deposition with the sandstone.

At Siebengebirge, on the eastern side of the Rhine, below Coblentz, are deposits of blende. At Altgluck they are intercalated in lower Devonian shales and sandstones, striking N. 40° E. The gangue is principally quartz, and the ore is almost entirely blende, with some galena. The deposit is crossed by a trachyte dike, near its southwestern end, and though not faulted, becomes rapidly impoverished beyond. With depth it also splits up and becomes diffused.

The deposits of the Eifel group of the Moselle are likewise in Lower Devonian rocks, and are similar to that of Altgluck. Veins occur here running in different directions, which are enriched at the intersections.

Near Gladbach, a few miles east of Cologne, zinc deposits occur in pockets and depressions in Devonian magnesian limestones associated with clays. They have much the appearance of having been washed in mechanically. They are overlain by later deposited beds of clay and shale containing brown coal. The ores consist of fragments of calamine, smithsonite and galena, in Middle Devonian shales.

Near Olpe and Siegen, in the eastern limits of the district, about 50 miles east of Cologne, are veins carrying galena, blende and copper pyrite, associated with a gangue of spathic iron, and traversing Devonian schists and slates and graywacke. These are not productive deposits now, though they were worked as early as the 15th century.

Westphalia.—Westphalia, just north of Rhenish Prussia, has been an important producer of both lead and zinc ores. In 1881 nearly

34,000 tons of zinc ore and 10,700 tons of lead ore were produced; in 1890, 11,400 tons of lead ore. The most important deposits are those of Iserlohn at Brilon.

At Iserlohn the deposits occur along the contact between the Eifel limestones and underlying Lenne shales, both of Devonian age. The ores, consisting principally of calamine, smithsonite and galena, with blende at depths, associated with clay and sand, occur principally in irregular pockets or nests, sometimes connected; also in crevices which traverse the limestone in a network. The contact with the limestone is very irregular and the rock surfaces are rounded and decomposed; the contact with the shales is, however, sharp. Both calamine and blende are found replacing calcareous fossils, and this, together with other phenonena, show plainly the substitution of limestone by these ores.

The Brilon deposits are similar to those of Iserlohn; much of the ore is found in the limestone in crevices of very irregular shapes, associated with clay and pyrite.

Nassau.—This province, though not ranking now as a producer of zinc ore, has been a source of large lead supply. It is also a very old mining district, work having been in progress as early as the 12th century. In 1881, the output of lead ore amounted to 23,000 tons, and of zinc ore 14,700 tons. In 1890, 13,400 tons of lead ore were produced.

About Holzappel and west of that place, to and beyond the Rhine, are the most important deposits. They occur in a group of veins, trending ENE.-WSW., and dipping from 50° to 80°; they traverse Lower Devonian shales and graywacke, which strike NE. and dip SE.; accompanying this is a talcose clay called "Weisses Gebirge," which Von Groddeck pronounced probably an altered diabase. Outside of the group of veins are basaltic dikes. The veins are very irregular, and have sharp deflections. They consist generally of several branches, aggregating 3 to 4 ft. in thickness. They are not absolutely continuous individually, but belong to a continuous system. The gangue is principally quartz; brecciated fragments of country rock are also included. The essential metalliferous mineral is galena, and with this are associated blende, copper pyrite and spathic iron, also barite, calcite and dolomite, mixed irregularly or arranged in bands. Near the surface oxidized products are found. The lodes are characterized by rich and poor sections or zones, and are not everywhere remunerative.

Hanover, or the Harz.—The classic region of the Harz mountains of Hanover, in eastern Prussia, has been known as a center of mining for nearly a thousand years, and vast quantities of argentiferous galena, along with other ores, have been produced. Zinc ores occur as accessories in some of the deposits, but the region is not classed as a zinc producer. For the year 1880 the Harz is credited with a production of 48,800 tons of lead ore; for 1890 with 37,400 tons. The whole region has been much disturbed by flexing and by the intrusion of igneous rocks, and the ore deposits are intimately connected with these disturbances. The principal deposits which call for attention here, are those of Rammelsberg, Clausthal and Andreasberg.

The Rammelsberg ores occur in Lower Devonian slates and sandstones. The deposit is a peculiar one, and has been considered a vein of segregation, a true vein and an interstratified bed. Authorities seem now agreed in assigning it to the last class. It occurs in strata which have an overturned dip of about 45° SSE., with which the ore body conforms. In the direction of its length it has been exploited over a mile and a half, and in depth nearly 1000 feet; the thickness is generally about 50 feet, though sometimes near 100 feet. The ores are sulphides of iron, copper, lead and zinc, intimately mixed, though sometimes distinctly banded; small amounts of barite, calcite and quartz occur as gangues. The present hanging wall, which was, before the overturn, an underlying bed, is impregnated with ore for a considerable thickness. The explanation offered for the deposit is that it was formed through the impregnation of sediments at the time of their deposition, by metalliferous solutions from depths, and was subsequently overturned with the flexing of the country rock.

Clausthal includes a large number of mines operating deposits in foliated and faulted Devonian and Lower Carboniferous clay slates and sandstones. The rocks dip S. E., and are traversed by fault fissures. The ores occur in lodes, which are in groups of bifurcating and ramifying veins; they have S. E.—N. W. trends. The gangue consists largely of a breccia of country rocks with a dark clay or shale between the masses and fragments, apparently resulting from attrition of the walls. This is traversed by a stockwerk of veins composed of calcite, dolomite, spathic iron, quartz and barite, carrying argentiferous galena and some blende and copper pyrite; the blende increases in quantity with depth, while the lead decreases. These composite veins are often 100 feet and more thick; they have generally steep dips.

At Andreasberg we have a narrow belt of Silurian slates and schists traversed by greenstone dikes. Lodes of several classes occur here, and some, of great extent, are entirely barren of metal. Two systems are recognized, forming a net-work of argentiferous veins, none over 2 ft. thick. They are very irregular, however, expanding and contracting and changing in direction and dip; they are partly filled with rock and clay containing calcite and a little quartz, argentiferous galena, blende, and compounds of silver and arsenic.

Saxony—Erzgebirge.—The Erzgebirge form a natural boundary between Bohemia and the kingdom of Saxony. Many famous mines occur along both sides of this range of mountains. Mining was begun here as early as the 12th century, and has continued with intermissions since, the region including the most important mining centers of Europe. Lead ore, which is all argentiferous, has been produced in large quantities, the ouput of 1890 being 35,000 tons. Zinc ore also is mined, but in comparatively small amounts—the production of blende in 1891 amounting to little over 1000 tons. In addition, silver, gold, copper, bismuth, nickel, cobalt and other substances are produced in merchantable quantities.

The country rocks are gneisses, overlain to the west by mica, schists and clay slates. These are traversed by dikes of porphyry and other igneous rocks which have accompanied successive disturbances of the region, which took place at intervals from early Paleozoic to Tertiary times. The ore deposits are intimately associated with these rocks, and are considered to have been derived from heated subterranean waters which accompanied or followed the eruptions. Representatives of such waters still exist in the thermal mineral springs of the region. Over 1800 lodes are recognized, of which more than two-thirds are worked for lead in part.

The Freiberg district is the most important. The ores occur in lodes traversing the gneiss. Over 800 are known to exist. They are divided into several groups, according to their contacts and courses. The latter are either N. E.—S. W., S.—N. or N. W.—S. E.; they thus frequently intersect. The lodes carrying galena generally contain blende, and also copper and iron pyrite and various silver ores; the gangue minerals are quartz, dolomite, and in one set of lodes largely barite, with some fluor spar and quartz. The materials of these veins are sometimes regularly banded, elsewhere brecciated, and also line

largely drusy cavities. The thickness of the veins is seldom over 1 ft. or 2 ft.

At Berggiesshnebel the ore deposit is in dark-gray clay slate, traversed by quartz porphyry. The deposits are from a few inches to 20 ft. thick, and are parallel to the stratification, like beds.

At Bleistadt lodes occur in mica, schist and gneiss, with courses N.—S. or W., S. W.—E. or N. E. They are 1 ft. to 2 ft. thick. They contain galena, blende and pyrite, with cerussite and pyromorphite as decomposition products, in a gangue of clay or quartz. The ore occurs in bands or nests.

In the Schneeberg district similar lodes carry galena and blende, with many other minerals. Some containing large quantities of barite were formerly worked, and were rich in lead ores.

About Katharinenberg the lodes contain galena and blende associated with copper and silver ores. At Johanngeorgenstadt and Eibenstock, lead ores are mined together with silver and cobalt ores. At a number of other localities valuable deposits have been worked, and, did the purposes of this chapter justify it, it would be of interest to describe them, as well as to add more concerning those already mentioned. The above will, however, give a general conception of the nature of the occurrences of lead and zinc ores in the Erzgebirge.

Baden.—In the duchy of Baden deposits containing both lead and zinc ores occur, many of which have been the scene of extensive and profitable mining. A few of these we will refer to briefly.

At Weisloch, in northern Baden, is a deposit of lead and zinc ore which is of special interest in connection with those of Missouri. It was worked for galena as early as the 11th century. The country rocks are limestones and dolomites of Lower Triassic age known as the *Muschelkalk*, in the upper beds of which the ores are found. They occur in irregular enlargements of vertical fissures, at the intersection of these with stratification planes of the limestones at different levels; they extend out along these planes in sheets and pipes and irregular masses, sometimes over 20 feet thick, for distances of 2000 feet. The ore consists of smithsonite, blende, galena, marcasite and limonite. The smithsonite often replaces fossils, and is pseudomorphous after calcite and has replaced the limestone; it also contains cadmium, sometimes as much as 3.36%. These ores occur generally with a red clay. The vertical fissures are often only a few lines thick and are filled with clay. Dr. Adolph Schmidt, who was formerly an assistant of the Mis-

souri Geological Survey, has made a special study of these deposits, and concludes that they have originated, in most cases, by direct filling of pre-existing cavities, though the removal of the limestone must have been simultaneous in some cases. The cavities he attributes to orographic movements. The original ores were sulphides deposited from solutions infiltrating from above [*200, p. 502*].

In the Kinzig valley, in the northern portion of the Black Forest, lodes, 6 ins. to 2 ft. thick, occur in granite, carrying galena, copper pyrite and silver ores, in a gangue of barite, dolomite, calcite and fluor spar. These and other deposits of the valley are pockety and were never very profitable.

Near Salzberg, in the southwestern corner of the Black forest, are also thin lodes carrying argentiferous galena in barite and quartz.

Near Badenweiler is a contact vein, at times as much as 12 ft. thick, between Devonian sandstone on the one side and granite porphyry on the other. Argentiferous galena, copper pyrite and other minerals are found here, in a gangue composed principally of barite, but containing also fluor spar and quartz. In the Muster valley similar lodes occur.

In Alsace, across the Rhine from Baden, highly argentiferous galenas are found near Markirch, in veins traversing gneiss; others, near St. Nicholas, are in Devonian rocks; others occur in the Trias in northern Alsace.

In Lorraine, near St. Avola, and at other points, deposits of lead and copper ores similar to those of Commern are found in Triassic sandstones.

In Wurtemberg, deposits of argentiferous galena are known. In the Bavarian Upper Palatinate, galena and cerussite are found impregnating the Keuper (Lower Triassic) sandstones.

GREECE.

Both lead and zinc deposits occur in Greece, and have been mined in large quantities. The lead ore is all argentiferous, much of it very highly so: the lead of Laurium contains as much as 1% of silver. The deposits are thought to have been worked as early as 1200 B. C. Mining was certainly in progress on a large scale as much as 2500 years ago—the period of greatest activity being between 600 and 450 B. C. During this time as many as 15,000 slaves were employed at the Laurium mines. After that, mining was prosecuted at intervals in a desultory way, until

the 1st century A. D., after which the deposits were abandoned until 1864. From the slag heaps of this mining it is estimated that over two million tons of lead and 270 million ounces of silver were produced. The deposits were reopened for extensive operations about 1876, and as is shown in the tables, have since yielded and continue to yield large quantities of zinc and lead ores. Outside of the deposits of Laurium, others are known at a number of other localities, but the former entirely overshadow all others.

Laurium.—The mines of Laurium are situated at Attica, a few hundred feet above sea level. Many of the workings extend nearly down to this level, which fixes a limit below which the deposits cannot be worked.

The country rocks consist of strata of schists and limestone, varying in thickness from 200 to 300 ft., and aggregating about 1200 ft. These are profoundly disturbed and much metamorphosed, and are traversed by dikes of igneous rocks. As a result, numerous fissures traverse the rocks, which may have served as channels for ore-bearing solutions. One main anticlinical flexure crosses the region in a direction N. 15° W. The main ore deposits are on the east slope of the flexure. The strata are of undetermined age, but are probably Silurian, though some have considered them Cretaceous; they probably lie on granite and are overlain by Tertiary and Quaternary deposits. Three series of limestone beds and two series of schists are recognized. The limestones are crystalline, are dense like lithographic stone, or are saccharoidal; the schists are in part argillaceous, contain quartzose layers and mica, talc and fissile limestone.

The ores occur principally along the upper and lower contacts of the bottom stratum of schist with the contiguous limestone; they are also found in pockets or veins running transverse to the interstratified deposits. These are of funnel-shaped cross-sections, penetrating the sub-jacent or super-jacent limestones. Crevices also penetrate the schists, but contain ore irregularly and only occasionally.

The ores are principally galena, cerussite, blende and smithsonite, with sulphides of copper and iron. The gangue is largely carbonate of iron or ocher. The deposits of the upper contact are mostly smithsonite, and are less pure and rich than those lower down, the limestone being much corroded from surface action. Along the lower contact, galena occurs frequently as a central band in the deposit, separated from the calamine on both sides by a variable thickness of ocher;

blende is also found at this horizon. The derivation of the smithsonite here from blende is thought doubtful by Posepny, as necessitating the action of surface agents below the limits they probably would have reached.

At Camoresa, the center of mining here, such a metalliferous deposit is developed over an area of more than 2 square miles, with a thickness of from 3 to 22 feet.

The generally accepted explanation of the mode of formation of these ores is that of Mr. Huet, that they originated from solutions issuing from depths along fissures; that these solutions were arrested by the lower schist and dikes, and spread out along the contacts, depositing the metalliferous compounds as incrustations and by substitution; that they also traversed this schist along minute crevices without leaving deposits, and formed less pure bodies of ore beyond, along the upper contact.

Similar deposits are referred to as existing elsewhere in Greece. On Mt. Hymettus zinc ores are found in limestone. Argentiferous lead ores with copper ores occur in the limestone and mica schist of Karysto. Further, there are numerous veins of argentiferous lead ores in a number of the Grecian islands; also in Macedonia and Asia Minor.

FRANCE.

France, though not among the first of European nations in the production of lead and zinc ores, has during recent years increased her output very greatly, so that the annual productions are now large, amounting in 1891 to nearly 30,000 tons of lead ore and to over 60,000 tons of zinc ore, principally from southern and northwestern France. The lead ore, like most of that of Europe, is argentiferous, while the larger part of the zinc ore is smithsonite or calamine. The Phœnicians and Gauls are thought to have mined argentiferous lead ores in France before the Roman conquest, and there is no doubt about the Romans having pursued mining here; but actual records of operations do not extend back over six hundred years. The principal regions of mining are in the Vosges, the plateau of Central France, the Pyrenees and the Alps; in past years important lead mines were operated in Brittany.

Vosges.—The department of Vosges, situated on the eastern border of France, adjacent to Alsace, was, in the past, the scene of extensive

mining. Operations began here as early as the 14th century. During the present century little or no work has been done.

One of the most important deposits was that of the St. Marieaux mines. Here, what is known as the Lacroix lode is as much as 60 ft. thick, and was worked along its strike in a N.–S. direction for a distance of two and a half miles. It is nearly vertical. The filling consists principally of debris from the gneiss wall rocks. Through this mass the ore runs either in strings or branches in the form of a stockwerk, or it occurs in one vein as much as 3 ft. thick. The metalliferous minerals are argentiferous galena and various silver ores. Since its discovery in 1315, this deposit has been worked at intervals up to the year 1833, when it was abandoned, and has not been reopened since.

In addition to this there are numerous other argentiferous lead lodes in the Vosges of minor importance, which space will not permit us to describe.

The Plateau of Central France.—This region, embracing all of southern France lying between the Pyrenees and the Alps, is the source of most of the zinc ore and of a large part of the lead ore now mined.

In the department of Gard the output of zinc ore is particularly large, amounting to over 26,000 tons in 1891. At the mines of Les Malines two classes of deposits are recognized. The first, from which most of the zinc ore is obtained, occur in dolomites of Middle Jurassic age, in and along crevices, in caves or in large masses, which frequently enclose partially unaltered masses of the rock. The ores consist of calamine, smithsonite, blende, hydrozincite, galena, anglesite and pyromorphite. The second class of deposits consists of a large vein traversing primitive limestone in an E.–W. direction, with a southward dip. This is thought to be probably the channel up which the ore solutions originally flowed. Along the outcrop it has been opened for 1500 ft. It consists of an aggregate of narrow, parallel and interlacing fissures, enclosing galena, blende and pyrite in a gangue of barite.

At Clairac, near Alais, a series of well-defined veins marking a sharp fault occur, traversing Lower Jurassic limestone in a direction N. 45° W. They are filled with blende and other zinc ores, and contain galena in pockets. In thickness they vary from 6 ins. to 3 ft. All of the Alais group of veins are lean and carry barite.

The Roussan group includes irregular bodies of mineralized Jurassic limestone, which become impoverished with depth.

At Les Avinieres "calamine" impregnates a bed of dolomite which lies between an overlying stratum of marl and an underlying bed of barren, siliceous dolomite. In evidence of replacement, blocks of unaltered dolomite are found in the mass of the ore. The richest part of the deposit is in the central portion of the dolomite, near a series of fissures running nearly N.–S. In the east the dolomite is cut off by a fault. The deposit has been worked about twenty years, and is now nearly exhausted. Other similar deposits occur at different horizons in this district of the department, and some of them contain blende. In the department of Drome, zinc ores are mined near Merglon, in the Piemart mountains. Pockets of smithsonite which give out with depth are found here in Middle Jurassic limestone. Ores occur also in a large, nearly vertical vein, which is as much as 30 ft. thick between solid walls. It is filled largely with calcite, replaced by smithsonite in places; blende and galena are found only occasionally.

In the adjoining department of Ardeche are also producing veins of blende and galena.

In the department of Lozere, near Violas, are deposits which, from evidences yet remaining, were worked at a very early date. Recent developments reach, however, not much over a hundred years back. Nine systems of metalliferous veins are recognized, occurring mostly in mica schists. The oldest of these contain pockets of argentiferous galena in barite gangue; another system is filled largely with detrital materials, surrounded by calcite and barite containing highly argentiferous galena. Other systems have a quartzose gangue and are nearly barren. The richness of these veins is found to diminish with depth. Their annual yield at present does not amount to over a few hundred tons.

In Puy-de-Dome, at Pontgibaud, is what has been one of the most important deposits of argentiferous lead ore in France. Great fissures occur here, which are connected with flexing and the ejection of granulite in Carboniferous times. The ores occur in lodes in gneiss and granite. These range up to 55 ft. in thickness. They are filled with masses of the country rocks surrounded by a breccia of smaller fragments and clay. Through this gangue run veins of quartz containing galena, a little blende, barite and rarely calcite. The ores are confined

to chimneys or zones from 150 to 450 ft. long, and extending in column-like forms to depths. The productive vein filling averages from 5% to 6% of lead. The production of lead ore in 1891 amounted to 2600 tons.

In the Forez mountains veins occur in gneiss and granite. The most important contain pockets or chimneys filled with argentiferous galena, blend and pyrite in a gangue of quartz and barite.

In Haute Loire, near Aurouse, mica schists are traversed by veins of argentiferous galena. These contain large quantities of barite near the surface, but are quartzose at depths, and most of the galena is associated with the quartz. Fluorspar becomes prominent also in the deeper portions, and contains no ore.

In Correze deposits near Chabrignac include: 1. Veins running N.-S., traversing crystalline schists, Coal Measure, Permian and Triassic grits, and containing barite and pyrite with pockets of galena, only one of which veins is workable; 2. other veins, very irregular and thin, carrying galena, pyrite, barite and a little calcite and quartz; 3. impregnations of Permian grits, very much diffused.

In Avalon in Morvan, galena, together with carbonate of copper, barite and quartz, are found impregnating Triassic and Jurassic strata. Fuchs and DeLaunay speak of such occurrences as common in the Central plateau.

In Aveyron, near Villefranche and Najac, lodes occur in mica schist, running S E.–N W. and extending into granites and into Triassic rocks. They are connected with eruptions of porphyry. They are filled with saccharoidal quartz, barite and jasper, containing argentiferous galena and copper and iron pyrites. Much of the galena is disseminated in the saccharoidal quartz.

Similar veins, though containing more barite, occur near Aspri-eres.

At Corbieres, irregular lodes of barite, with copper and lead ores, occur in Cambrian clay slates and gneisses, with intercalated beds of granular limestone, all traversed by eruptive granites and porphyries.

Near Milhau, lodes are found in Lower Triassic beds, consisting of quartz containing granular galena, often disseminated, with, rarely, a little barite.

The Pyrenees.—In almost all of the departments of the Pyrenees lead or zinc ores are or have been worked. In 1891 they produced over 5000 tons of zinc ore and nearly 700 tons of agentiferous galena.

In Ariege, the Sentein is one of the most important lead mines in the mountains. The ore occurs in a lode along the contact between Lower Carboniferous limestone, as the foot-wall, and schist as a hanging wall. The trend is N. 10° E. The contents of the lode are quartz and calcite, containing argentiferous galena, cerussite, anglesite, blende and calamine. Near St. Girons are veins which were worked during the Roman period, and to a small extent recently. They are separated into four systems, two of which have an easterly course, and contain argentiferous galena, with blende, calcite, spathic iron and sometimes quartz.

In Haute Garonne, near Arguts, numerous but thin metalliferous veins are found, traversing Silurian slates and schists, containing principally blende, with some galena.

In Haute and Basses Pyrenees are also deposits which yielded some 3000 tons of zinc ore in 1891.

In Savoy, in the Alps, argentiferous galena is found in bedded veins. The deposits were exploited early in the century.

In Var, the extreme southeastern department of France, some 23,000 tons of roasted calamine were produced in 1891, according to Fuchs and DeLaunay. The principal mine is the Bormettes, opened about 10 years ago; no descriptions of the deposits have been accessible to the writer.

In the island of Corsica veins of argentiferous galena in granite are found.

Brittany.—The deposits of Brittany were in past centuries among the most important producers of argentiferous lead ore in France, and though the same deposits do not now continue to yield ore, others, newly developed, continue to maintain the prominence of the region.

In the department of Ille-et-Vilaine, the Pontpean deposit is the most important. It consists of a strong vein, running N. 20° W. in Silurian schists, composed of quartz and clay, containing a series of veins or veinlets of galena and blende, both argentiferous, with pyrite and compounds of silver. These minerals are of uneven distribution and are intimately mixed with the matrix; frequent horses of country rock occur. The thickness of the vein varies from an inch to 25 ft.; 7 ft. is perhaps a fair average. The deposit is apparently connected with a diorite dike which cuts through the schists and flanks the vein. It seems to have caused a reopening of the fissure and a subsequent deposition of the ore. The silver contents diminishes with depth.

The production in late years has been about 7000 tons of argentiferous galena and 2000 tons of zinc ore.

At La Tauche is a vein in granite containing both galena and blende.

In the department of Finisterre are the once very important deposits of Huelgoat and Poullaouen. They were worked continuously during the reign of Louis XIII and from that time to 1868, when they were abandoned. The ores occur in veins cutting granites, and Devonian and Carboniferous schists. The productive veins ran N.–S., the unproductive E.–W. At Huelgoat the principal vein was exploited for a length of 3400 ft., and to a depth of over 900 ft. It traverses all of the country rocks nearly at right angles. The thickness varies from 2 ft. to as much as 75 ft., though 12 ft. is about an average. The gangue is quartzose. The metalliferous minerals are argentiferous galena, blende, pyrite, and, near the surface, oxidized lead ores with chlorides, iodides and bromides of silver and some native silver. At Poullaouen, the main lode was opened lengthwise for a distance of 4500 ft. and to a depth of 600 ft. It varied in thickness from a few inches to 150 ft., though, on an average, it was about 6 ft., but the limits are not well defined. The course is NW.–SE., and the dip is 45° NE. The country rocks strike ENE. and dip about 45° S.; they consist of clay slates, quartzites and greenstones. The ores are principally galena and blende, with pyrite in a quartzose gangue, which extend in a network of veins through the rock. These minerals are restricted to courses or zones.

ITALY.

Italy, as already remarked, is an important producer of zinc ores, and the yield of argentiferous lead ore is also large. The great bulk of the ore comes, however, from the island of Sardinia. Mining was in progress here during the Roman period, and even before this by the Carthaginians and Phœnicians. During the past thirty years the annual production of lead ore has averaged nearly 30,000 tons, and in 1890 it was 35,800 tons. The zinc ore produced in 1890 amounted to 127,000 tons.

Sardinia.—The importance of Sardinia as a mining center may be judged of from the fact that of the total production of Italy in 1890, 35,200 tons of the argentiferous galena and 110,400 tons of the zinc ore came from that island. Of this, fully nine-tenths came from the

mines about Iglesias, in the sothwestern corner. Near Sarrabus, in the southeast, small quantities of silver lead ores are also obtained, and near Murra, in the northwest, also.

Iglesias is thus the great lead and zinc-producing center of Italy. The mines surround that place to the south and west and extend some fiifteen miles north of it. Geologically, the country is composed of a great central mass of granite, surrounded by Silurian schists and gray-wackes, Cambrian grits, quartzites and schists and a "Metalliferous" limestone or dolomite of probable Silurian age. Deposits of galena, blende, smithsonite and carbonate occur in all of these formations. They are found principally along the contacts between limestones and schists. They occur in crevices or along the contacts between two different limestones or in one stratum of limestone. The different ores are often intimately associated, and are closely related in origin. The percentage of silver is found to increase with the irregularity of the lode and to decrease with depth, while the percentage of blende increases. The large deposits of carbonate and silicate of zinc are found near the surface.

At Montevecchio is the largest lead mine, and one of the most important in Europe. It was worked by the Romans. It is the northmost of the group. Several lodes occur here which cross the Silurian schists with a dip of 65° N. The principal one is, at times, as much as 180 ft. thick, and the quartzose gangue forms a great wall-like ledge at the outcrop. Veins of galena occur along the foot and hanging walls, and also in lenses in the interior of the gangue; iron and copper pyrites and barite are found; the proportion of blende increases with depth.

The San Giovanni mines, two miles southwest of Iglesias, were worked in the 14th century. The ores occur in lodes, principally along contacts between limestones, in nearly vertical positions. The lodes are very irregular, they are filled with a gangue of quartz, limestone, clay and barite, which contain argentiferous galena and some blende in columnar masses or zones.

The Malagalzetta deposits, a few miles north of Iglesias, consist of lodes in the Metalliferous limestone containing lenses of galena, and also of zinc ores in shallow pockets near the surface.

The Monteponi mines, about a mile southwest of Iglesias, are the oldest, and were worked successively by the Carthaginians, Romans and Spaniards. They have attained greatest importance since 1840.

The lead ores occur in what are termed columns, which follow the steeply dipping limestone strata downward, being somewhat flattened or enlarged in the plane of stratification. The filling is principally galena and a little calamine, with nodular pyrite, in a gangue of clay and calcite; calamine also extends into the limestone walls in veinlets. The principal zinc deposits, consisting of both smithsonite and calamine, occur further north at another horizon; these ores are found along the stratification, in crevices and in masses of breccia, exhibiting good evidence of having replaced the limestone. The deposits taper out with depth. The ore contains only about 33% of zinc, and carries much iron oxide; some cerussite is also found.

At Nebida, five miles west, are great columns or chimneys of calamine in limestone as much as 60 ft. in diameter, and extending to depths of 600 ft., as if filling caverns. Veins of galena and calamine are also worked, and the wall rocks are much mineralized and replaced by the zinc ores.

The Malfidano mines, about eight miles northwest, are also important. "Calamine" is found interstratified with the limestone, and sometimes in alternating layers. At Caitas the ores follow and have replaced the bedded limestone; they are traversed by a great fissure, 100 ft. across, filled with a breccia of limestone and clay. The "calamine" occurs on either side, in cone-like or columnar lodes; at depths, blende and some galena are found.

At Sarrabus, in southeastern Sardinia, are important silver-lead ore deposits, which, though first worked in 1622, were not really developed until 1870. The country rock consists of Silurian schists metamorphosed by granite, which have been disturbed at various times since the post-Silurian. The ores occur in interstratified lodes, which range up to 6 ft. in thickness. The filling is irregular and contains barite, calcite, galena, a little blende, other silver ores and native silver. The ores are concentrated in zones, which are as much as 1200 ft. long.

Piedmont.—In the Piedmontese Alps the Pesey and Macot mines were worked for many years and produced both lead and silver. At the Tenda mine, in the Turin district, granular galena occurs associated with blende and pyrite.

Lombardy.—In the Milan district lead ores occur in veins in crystalline schists, and also in massive deposits and pockets in Triassic do-

lomite. At Argentiera, near Aurongo, zinc ores are found in irregular deposits in Lower Triassic slates and dolomitic limestones.

Tuscany.—In the Aupanian Alps, east of Carrara, are lodes of argentiferous galena. At Bottino, the site of old Etruscan and Roman works, are deposits of argentiferous galena, with antimony compounds in quartzose lodes, traversing Paleozoic schists. Some calcite and siderite, together with blende and pyrite, occur in this lode. The ores are confined to veins and zones in the lodes.

In Sicily are ancient lead mines, which were reopened in 1747, but are now abandoned.

RUSSIA.

The lead and zinc ores of Russia have been derived almost entirely from Poland and Siberia, and from a few mines in the Ural and Caucasus mountains. Recently, deposits on the Mourman Coast of the Government of Archangel have been developed. In South Russia, argentiferous lead deposits of the government of Ekaterinoslav and in the Donetz basin will probably soon be exploited [*95, vol. ii, p. 414*]. Evidences of very early mining (150 B. C.) are found in Siberia, but the deposits were not made known generally till the end of the 17th century. In Poland, large amounts of lead were produced in the 16th century. In 1882 the production of zinc ore in Russia amounted to over 100,000 tons; but during recent years it has sunk to about 50,000 of low-grade carbonate and silicate. The production of lead ores during the past ten years has varied from 32,000 to 42,000 tons annually.

Poland.—The Poland deposits are extensions of those of Upper Silesia of Prussia, already described. They have been so far but little developed. The principal mining is near Olkusz and Boleslaw, where large amounts of lead were produced in the 16th and 17th centuries. Operations are confined to one dolomite mass, about which innumerable pits 45 to 75 ft. deep have been sunk. The "calamine" is massive and occurs in a breccia composed of nodules and masses of dolomite surrounded by the ore. Blende and galena occur along a network of fissures.

Near Kielce and Checiny, lead and copper ores occur in lodes in Devonian quartzites. They were worked in the 15th century.

Siberia.—In the province of Irkoutsk, at Nertschinsk, are deposits of argentiferous galena with tellurides of silver and lead, in limestones and schists. The ores occur in stockwerks and also in the form of lenses in limestones.

In the western extension of the Altai mountains, in Tomsk, are a number of lodes carrying argentiferous galena. The most ancient and celebrated of these is near Kolivan. The lodes here contain ores of silver, lead, zinc, gold and copper. They occur generally in Silurian, Devonian and Carboniferous rocks, and rarely in crystalline schists. They cut across and are also interbedded with the strata, are of irregular shapes and pass into deposits of massive form. They are filled with barite and quartz, containing sulphides of the metals, which are oxidized to considerable depths beneath the surface. The thickness of the lodes varies from 6 to 300 ft., and the ores are diffused through the gangue. The rocks are traversed by eruptives which are thought to have some relation to the ore bodies.

In the Donetz basin of South Russia, a large number of promising veins have recently been found. The ores are sulphides.

Caucasus.—In Ossetie, north of the mountain range, lodes are known, composed of a gangue of quartz, barite and limestone, containing galena, blende, copper and iron pyrite and their oxidation products. In the Caucasus mountains argentiferous galena and some zinc are associated with copper-bearing lodes.

On the upper waters of the Kouban the discovery of large deposits of lead and silver ores has been announced during recent years. Up to 1892, 44 veins had been discovered. Of these, 11 have been examined, and showed average lead contents of 48%. Many are large and favorably located for work.

SPAIN.

Ranking far ahead of all other European countries in the production of lead ores, and standing third during recent years in the output of zinc ores, Spain deserves extended notice. The lead ores are all more or less argentiferous; the zinc ores are principally smithsonite and calamine.

Lead mining in Spain is undoubtedly of great antiquity. At the time of the Phœnician settlement of Cadiz in 1100 B. C., trade in lead and other metals was established. After this, mining was conducted under the Carthaginians, Romans and Moors. Pliny, in the 1st century A. D., describes the mines minutely. After the expulsion of the Moors, mining fell into decay. In the 16th century it was resumed, and has continued up to the present time, the greatest impetus being given in 1825, through the decree of Ferdinand opening the mining country to the

enterprise of foreigners. Since that time the production of lead ore has been very large, and, during recent years, it has been simply enormous. In 1889, the output was 600,000 tons, and, in 1891, 520,000 tons, and, during the preceding twelve years, it had averaged over 500,000 tons. Zinc ores are, of course, of quite recent development; those of Santander, which now furnish the great bulk, were discovered in 1852. The output in 1890 was over 80,000 tons, and, during the preceding ten years, it averaged about 60,000 tons.

The principal lead ore deposits are at Linares, in the province of Jaen, at Cartagena and vicinity in Murcia, Sierra Almagrera, in Almeria, Sierra Gada, Horcajo and others in Ciudad Real. Zinc ores come principally from Santander, though the Cartagenian and other mines in Murcia produce large quantities.

The following table, obtained from volume II of the Mineral Industry, gives the production by provinces:

PRODUCTION OF LEAD IN SPAIN ACCORDING TO PROVINCES.

(In metric tons).

Year.	Almeria.	Badajoz.	Cuidad-Real.	Cordoba.	Guipuzcoa.	Jaen.	Malaga.	Murcia.	Total.
1881	19,067	932	35	10,812	8,308	4,940	3,731	42,798	90,672
1882	17,391	963	1,786	14,776	8,680	4,977	3,340	36,426	88,339
1883	20,991	1,368	2,480	25,730	8,050	5,447	2,550	32,688	99,304
1884	15,444	1,203	3,723	16,179	7,500	....	2,844	36,411	83,304
1885	10,857	1,003	3,088	12,656	7,042	17,661	2,956	33,352	88,615
1886	8,013	650	3,372	16,897	7,196	27,798	3,610	38,406	105,942
1887-88	14,028	270	2,589	35,720	8,520	32,558	3,354	48,394	145,433
1888-89	11,333	279	....	20,610	7,267	25,550	2,873	63,546	131,460
1889-90	19,611	....	....	17,616	6,385	28,361	2,314	116,895	191,182
1892*	18,000	....	2,000	18,600	5,500	35,000	....	96,024	175,124
1893*	21,000	....	2,500	19,000	5,500	40,000	....	100,500	188,500

* Reported by Señor Don Roman Oriol.

Linares.—The Linares mines (with the possible exception of the Broken Hill mine in New South Wales) rank at present the first in the world as lead producers. They are situated in the province of Jaen, in northern Andalusia. They were worked as early as the time of the Phœnicians. In 1867 the production of lead ore amounted to 44,000 tons; rose to 132,000 in 1881, and was 128,000 in 1892. The ores are worked upon a very large number of small concessions, and the methods are pronounced crude and short-sighted. Nearly 800 mines are worked, employing 7000 individuals. The area mined is about 14 by 12 miles square.

The country rocks consist of a nucleus of granite, surrounded by Cambrian and Silurian schists and quartzite. These are all traversed by a great number of regular and persistent lodes. They are overlain by Triassic and

Miocene, rocks into which the lodes do not penetrate. The lodes are generally nearly vertical, and ores occur in them in zones or columns, which increase and diminish in richness with depth.

Two principal groups of mines are distinguishable, those about Linares and those about Carolina. The lodes of the former are principally NE.-SW., and are always in the granite and extend into the Cambrian schists. The galena occurs in a compact form in a quartz gangue. Associated with this are cerussite, barite, calcite, clay, and little blende. The mean thickness of the lodes is 2½ ft., though they expand to 6 ft. They have been traced individually six miles. Faults are quite numerous, throwing the lodes.

The Carolina lodes are principally in an E.-W. position, and have not such steep dips. They are more prevalent in the schists. They are thicker and more regular, and have more barite as an accessory mineral. The copper ores associated with the lead ores are found to give out with depth. The ore in the granites are most abundant in the soft and more granular rocks.

Cartagena.—In 1888 the mines of the province of Murcia yielded 155,000 tons of lead ore and 8000 tons of zinc ore. The country rocks about Cartagena are Permian limestones at the higher levels, with schists below. The ores occur in veins, in pockets, in large masses and in interstratified beds. The stratified deposits consist of impregnated schists and replaced beds of limestone. In the schists, lenses of blende occur. Overlying the schists, in places, is a peculiar deposit, as much as 30 ft. thick, of silicate of iron with galena diffused through it. At the base of the limestone is found a bed of oxides of iron and manganese, overlying a deposit of argentiferous cerussite. In the limestone galena and other ores are found along crevices and in masses, associated with smithsonite and siderite. Large masses, known as *crestones*, formerly furnished enormous quantities of ore; they usually extended to the surface and were composed largely of siderite, containing galena in nodules and grains.

At Almazzaron and Aguilas are Silurian argillaceous schists and metamorphosed limestones, penetrated by trachytes and basalts. The trachytes are traversed by numerous lodes, some as much as 6 ft. thick, filled with decomposed trachyte, pyrite and argentiferous galena. The mines of these two groups and others of the vicinity produced, in 1892, 98,000 tons of lead ore.

Sierra Almagrera in Almeria.—In the extreme northeastern corner of Almeria are a number of lodes yielding lead ores, which were discovered in 1839. The principal of these is the Jaroso lode. This traverses mica schists and clay slates in a N.–S. course, and with a dip of 60° E. It is worked 2100 ft. along the strike. The greatest thickness was about 20 ft., at a depth of 110 ft. The gangue is principally cerussite, containing argentiferous galena; with these are found spathic iron, barite, celestine, blende, copper pyrite and other minerals. These are arranged in bands, often in great number. The combed structure is often beautifully developed. The mines of this district yielded about 32,000 tons of lead ore in 1890.

Sierra Gado.—The mines of Sierra Gado and Sierra Lujar, in southeastern Andalusia, were among the first worked after the decree of 1825, and in 1827 they produced 47,000 tons of lead ore. Latterly they have been little worked. Whitney describes the deposits as similar to those of the Mississippi valley, occurring in Lower Silurian limestones in lens-shaped massed, like amygdules in a limestone paste.

Horcajo.—The production of the Horcajo mines, in Ciudad Real, has increased greatly in late years. The annual production is now nearly 80,000 tons of highly argentiferous lead ore. The ores occur in lodes in Lower Silurian schists and quartzites, running N. 75° E. Two principal lodes have been so far exploited, one of them for some 3700 ft. in length and 700 ft. in depth. They vary in thickness from 1 to 2½ ft. The gangue is principally quartz, sometimes with calcite. The galena occurs in veinlets $\frac{1}{16}$ in. to 4 ins. thick.

At La Romana and Almagro, in the same province, and at Castuera and Pesarroya, in Badajos province, similar lodes in similar rocks were worked. Recently lead deposits have been opened in the provinces of Huelva and Seville.

Santander.—The zinc deposits of Santander are found in dolomitic limestones of Cretaceous and Jurassic age, and in Lower Carboniferous limestones. The former occur in crevices, segregations and in bed-like masses or impregnations. The ores are principally smithsonite, though calamine and zinc bloom are also found. They occur in clay and also enclosing masses of limestone, which they have evidently replaced and which they grade into. Blende is found at depths in concretionary forms with barite. Some galena is associated with the ores. The deposits are similar to those of Aix la Chapelle, Weisloch and Silesia. The principal deposit of this class is the Reocin; others

are the Mercadel, Udias, Orena and Florida [176]. The Picos de Europa mines are in disturbed Carboniferous limestones. The ores occur, in the Andosa deposit, in a series of parallel veins running S E.–N W., within a belt about a half mile wide, which has been traced over a mile in length. The thickness of these veins varies from a few inches to 32 feet. The ore is principally smithsonite, with 40 to 45% zinc. In the Aliva deposits, six miles west, the ore is mostly blende.

SWEDEN.

Sweden has two interesting deposits which call for notice here, i. e., the zinc deposits of Ammeberg and the agentiferous galena deposits of Sala. During the past ten years the production of zinc ore has varied from 60,000 to over 50,000 tons of zinc ore, and from 13,000 to 18,000 tons of lead ore, derived almost entirely from these two mines.

Ammeberg.—The Ammeberg mines are about 120 miles a little south of west from Stockholm, at the northern end of lake Wetter. The country rocks are Laurentian schistose gneisses, flexed and contorted. The ores occur in lenticular, flat bodies, occupying a nearly vertical position, and conforming to all of the undulations of the country rocks. Their average thickness is about 25 ft., though they expand to 50 ft. in places. They are exploited to depths of 600 ft., and extend horizontally hundreds of feet, but are of variable length at different depths. The zinc ore is blende, and this appears to have taken the place of the mica in the schists, so that the ore-body is often a mixture of blende, feldspar and quartz. Sometimes it is entirely blende, however. There is almost always a little galena and pyrite present. The ores are considered to have been introduced after the flexing of the country rocks and to have filled the resultant openings. In addition to the zinc ores, several hundred to a thousand tons of highly argentiferous lead ore have been produced annually.

Zinc ores are mined also elsewhere, in the provinces of Orebro and Kopparberg.

Sala.—The lead deposits of Sala were worked in the 6th century. They are situated about 60 miles northwest of Stockholm. The deposits consist of irregular masses of argentiferous galena intercalated between the beds of a large, lens-shaped mass of Primitive magnesian limestone. The limestone is traversed by trap dikes, and also by fault fissures known as *skœlars*, which are filled with a breccia cemented by calcite and talc, and containing galena, blende, pyrite, quartz and other

minerals. These fissures are as much as 60 ft. wide at the surface, but soon contract downward to a breadth of only a few feet. The outlines of the contained ore bodies are ill defined; they vary in thickness from a few inches to several yards. The adjacent rock is brecciated, and the ore is frequently disseminated through it or extends in along joints and crevices for several fathoms. The ores seem to follow the principal *skœlars* and to have some connection with them. The ore bodies have been variously regarded as beds, veins, and as impregnations by solutions derived from the fault fissures. Fuchs & DeLaunay favor the last interpretation. That they were formed after the intrusion of the dikes is plain.

OTHER EUROPEAN COUNTRIES.

Outside of the countries thus far considered, other deposits of lead and zinc ores occur at several points in Europe. None of these are, however, commercially important. Thus, in Portugal, especially in the southwestern part, are deposits of argentiferous lead ores which have been more or less worked. The principal of these is near Mertola; galena, cerussite and anglesite are found here, all carrying silver. No workable deposits of zinc ore occur, though highly argentiferous blende has been mined. In Norway a few tons of lead and zinc ores have been produced during different years.

THE LEAD AND ZINC DEPOSITS OF AFRICA.

So much of Africa is comparatively unexplored that the extent and distribution, or even the presence, of lead and zinc ores cannot be outlined. In South Africa lead ores are reported to occur in considerable quantities, although little mined [*177, p 69*]. Lead mines were exploited in the desert near the Red sea in the time of the ancient Egyptians. The best known deposits at present are those of Algeria and Tunis in the extreme north. How long they have been worked we are unable to say. The fact that lead was known to the ancient Egyptians lends color to the belief that these deposits may have been opened at a very early date. That those of Tunis were worked by the Romans is definitely known.

Algeria.—The deposits of Sakamody, Guerrouma and R'arbou are in the northern part of the province, about the Little Atlas mountains. They occur in a system of fissures in Cretaceous marls, schists and limestones, all more or less argillaceous. These are filled with blende and galena, "calamine" being in the place of blende near the surface. The gangue is often a limestone associated with barite and siderite. At Sakamody a schist breccia is found, with blende in the matrix between the fragments. The production of this mine is about 11,000 tons of zinc ore per year. At other points in the same district similar deposits have been worked to a limited extent.

In the department of Constantine, in the northeastern corner of Algeria, are the zinc mines Hammam N'bails and Ain Arko, of the Vieille Montagne company, which yield several thousand tons of ore annually. Near La Calle are the Kef-oum-Theboul lead mines, which yielded over 12,000 tons of argentiferous galena in 1876, as well as copper ore and blende. The mines of Cape Cavallo yield similar ores.

In the department of Oran the Gar-Rouban mine produces small quantities of argentiferous galena, and the Oued Moziz mine yields both lead and zinc ores.

Tunis.—A few miles west of the city of Tunis are deposits of argentiferous lead ore, which were worked by the Romans. They are in the Djebel Recas mountains and are known by that name. The country rocks consist of compact, non-fossiliferous, Lower Eocene limestone,

overlying unconformably argillaceous marls, mica schists and quartzites. The ores occur in lodes running about N. 5° W. The principal one is several feet thick. The metalliferous minerals are irregularly distributed in a gangue of crystalline limestone and breccia; this mineralized portion being only about 15 or 18 ins. thick. The minerals are galena, cerussite, blende and "calamine," all non-argentiferous.

THE LEAD AND ZINC DEPOSITS OF ASIA.

Silver-lead ores were mined by the ancients in Armenia, Chaldea, China, India, Persia and Syria. During recent times such have been worked in Asia Minor, India, China and Japan. Unfortunately, little information as to the distribution or conditions of occurrence is available. Zinc ore was used at a very early date in the manufacture of brass and other alloys. The metal zinc was first manufactured here and thence imported into Europe. It appears to have come from China, Bengal, Malacca and the Malabar coast. Deposits of zinc ore occur in India, but both zinc and zinc ores were imported from China.

In Assyria the mountains are said to abound in ores of iron, copper and of lead and silver. In Cyprus lead mines were worked by the Phœnicians. Ancient mining was conducted in Bucharia and Adelliyan. The Chalybeans worked deep silver mines in Bactriana. Lead ores are found in Arabia, in the Burmese empire [*177*].

Turkey in Asia [*144, vol. ii, p. 214*].—The low mountain district through which the Kizil Irmak winds, between Iskelib and Marsivan is known to be rich in veins of argentiferous galena, but only one small mine of it is worked, at Gumush-Maden, near Osmanjik. Nearly due south of this the Bulgar-dagh mine, in the Taurus, near Adana, were discovered and profitably worked during Egyptian occupation, but with the expulsion of Ibrahim Pasha the industry ceased. The Kebben-Maden mines, though rich and extensive, produced less than a ton of refined metal a year. Similarly the great deposits at Gumush Khaneh, near Trebizond, one the most productive of all the silver mines in Asia, are now almost forsaken. The annual product seldom exceeds 100 lbs. Other beds of this mixed ore exist at Alaidin and Bereketli, both near Kornieh, at Guebon and Piridjman, near Diarbekei, and in the islands in great abundance, in Imbros. Argentiferous galena has also been plentifully found at Akdagh-Maden, in the district of Tocat, but, though the veins crop up in the very midst of forests, and labor is both abundant and cheap, not an ounce of ore is extracted. It is also found on the slopes of Ishikdagh, in the pashalic of Angora, and at Dessek-Maden, within ten miles of the navigable Kizil Irmak.

India.—The lead ores of India are all argentiferous. They occur in beds, pockets or segregations, seldom in true veins. Many of these

deposits were formerly worked on a small scale by the natives, and they do not offer promise of ever warranting large operations.

In the presidency of Madras lead mining has been prosecuted at six localities. The Jungrumrazpilly mines were among the most prominent. They are now old and deserted. The ores were mined from pits sunk between beds of dark-gray siliceous limestone, traversed by seams or strings of bluish quartz. These seams of quartz fill fissures running NNE. and dipping 60° W. Through the quartz granula galena is disseminated. The lead contains about 12 ounces of silver per ton. These mines were early wrought by the Hindu kings of Bijanagar.

In Bengal lead ore deposits are described in four districts. In the provinces of Chutia Nagpur such occur in rocks of the metamorphic series. At Dhadka galena is found containing 60 to 80 ounces of silver to the ton, in lenticular masses with hematite and quartz, in lodes traversing mica schists and gneiss.

In the Central provinces seven localities are noted, the deposits of most of these being in metamorphic rocks; at two the galena is found in limestone. Near Jhunan a true vein or lode, 16 to 19 inches thick, traverses granite; it is made up of a quartz gangue through which argentiferous galena is sparsely disseminated.

In Rajputana lead mines occur in four districts. Near Ajmir the ore is in a number of parallel veins, traversing sub-metamorphic quartzites.

In Bombay, argentiferous galena is found at three localities. In Beloochistan there were ancient lead mines, and the remains of large works are now found there. In the Punjab Himalayas lead ores occur and have been worked a little; they are found in veins traversing slates and limestones. Near Swinji is a lode two feet thick, carrying galena, blende and pyrite, in a quartz gangue. In British Burmah lead ores occur, and in Native Burmah are large quantities. In Tenasserum are lead ores, in Lower Carboniferous limestones.

The principal zinc deposit of India is at Jawar or Zawar, in Udeper, state of Rajputana. It was described by Col. Tod as a tin mine, and he gives the annual revenue as over $100,000. The ore consists of smithsonite and argentiferous galena in Transition quartzites. It occurs in veins three to four inches thick, sometimes expanding to bunches. The zinc was distilled at the mines.

There is reason to believe that the mines of southern India, in the Karmel district, may have produced zinc. Abdul Fazl, author of Ain-i-Akbari, refers to brass as obtained in rivers of the Subah and Lahore.

China.—In China argentiferous lead ores are found in many provinces, but few are worked. At Tamchow and near Honkong are such. In Corea lead is found in considerable quantities.

The Tung-Chi-Lung lead and zinc deposit is about 250 miles [*45, p. 57*] west of Shanghai. It consists of a fissure vein tràversing blue gray slate. Its course is nearly E.–W., and it is nearly vertical. From shallow shafts, blende, galena and copper and iron pyrites were obtained.

The Je-Hol silver-lead district has recently been reopened [*45, p. 585*]. It was formerly worked by the Chinese. It is situated something over a hundred miles northeast of Pekin. The country rocks consisted of limestone and of gneisses, granites, mica schists, slates, etc. The limestones are metamorphosed in places and sometimes have a slaty cleavage. The main vein is entirely in the limestone. It strikes E.–W. and dips 50° to 75° N. Between distances of 500 and 16,000 ft. north of the main vain, are a number of veins interbedded with the limestone, dipping from 10° to 15°. They appear to be leaders from the main vein. The latter is 3 ft. wide at the 100 ft. level; 18 ins. at the 200 ft. level and pinches out at the east end. The pay-streak varies in thickness from ½ in to 2 ins., and is irregular in position. It consists of blende and argentiferous galena.

The Ku–Shan–Tzu mines, seven miles east of the last, are in hard gray limestone bounded on the east and south by schists. The vein cuts through the limestone in an E.–W. direction, dipping 50° to 70° N. Its width varies from 2 ft. to 12 ft., averaging 3 or 4 ft. The pay-streak, consisting principally of galena, is from 1 in. to 6 ins. thick.

Japan.—The lead deposits of Japan are neither numerous nor extensive. They consist of veins carrying galena, with silver and copper ores. Silver was first discovered in 667 A. D. Mining was prosecuted as early as the 8th centuary. In 1874 thirty-five mines produced little over 200 tons of lead ore, and of this, one mine produced about one-half. In 1892 the production was about 900 tons. The veins are thin and irregular. On an average they are less than 4 ins. thick, and 1 ft. is rare.

The Daira lead mine, in Yamamoto Koi, Akita Ken, is the most important [*148, p. 277*]. Over 350 ancient tunnels can be counted here. Ninety-four different veins are recognized within one and a half square

miles. They can usually be traced for several hundred feet. They are in fissures 1 ft. to 2 ft. thick, with an E.-W. trend and a dip of 50° or 60° S. The ore is galena, with blende, copper and iron pyrites and other sulphides, and carbonate of manganese. It occurs in lens-shaped masses about 150 ft. in diameter and 4 ins. to 7 ins. thick. The gangue is quartz or decomposed porphyry. The country rock is a dark blue argillite, with sandstone beds. It is sharply flexed and dips toward either the E. or the W. as much as 45° and 70°. Intruded dikes of white porphyry run parallel to the veins. The ore-bearing fissures extend into this porphyry.

The Yurap lead deposits are like those of Daira. They were abandoned some twenty years ago. The Toweda lead mines are quite small. Lead deposits occur also in Yeichi (?) in Kori-Shiga Ken. The Kosaga silver deposits of Akita Ken consist of irregular masses of argentiferous blende in white, feldspathic porphyry. The Mukoginza Ani mines adjoin the last, and the deposits are similar.

THE LEAD AND ZINC DEPOSITS OF OCEANICA.

Argentiferous lead ores are now mined in large bulks in Australia, though before 1883 very little was produced. Small amounts of zinc ore also have been mined, but the country cannot be classed as a zinc producer. In Tasmania argentiferous galena exists at the Penguin and near Mts. Roland and Claude. In New Zealand this and other silver ores are sometimes found in the gold reefs of Coromandel and of the Thames. Outside of this, no occurrences of lead or zinc ores are known to the writer in the islands of Oceanica.

AUSTRALIA.

During the year 1889 Australia produced about 23,000 tons of lead, and exported 17,000 tons of lead ore. In 1891 the production was nearly 150,000 tons of ore, carrying about 24,000 tons of lead. This comes almost entirely from the Broken Hill mines.

New South Wales.—The amount of silver mined in this province up to 1892 was very small. In that year extensive discoveries were made. The Broken Hill mines are at present the largest producers ot lead ores in the world. They are situated in the Barrier range. The deposits were discovered in 1883, and the production, which, in 1886, had already reached 11,500 tons, rose by 1890 to 222,000 tons of ore, averaging 16 per cent of lead and containing large amounts of silver. From January, 1855, to June, 1893, the company produced 183,334 tons of lead [*48, p. 85*]. The country rocks are Primitive gneisses and mica schists, with intrusive dikes. These are traversed by a great metalliferous lode, which splits into two or three parts near the surface. The course is NE.-SW., parallel to the strike of the schists. It has a prominent cap of iron ore at the surface, which passes deeper down into a gangue of ferruginous quartz, with barite and oxidized products of lead, copper and silver ores. At depths, the sulphides are encountered. The ore body crops out in large masses, somewhat lens-shaped. The thickness is often as much as 100 ft., though to the limits depths worked of 300 ft., the average is about 60 ft.

Other mines of the same district are Silverton and Thackaringa. At Boorook, in the New England district, and at Sunny Corner, near Bathurst, discoveries of ore have also been made.

In 1881 New South Wales exported...............	191	tons-silver lead ore.
In 1891 " "	92,283	" "
Total for decade......	269,472	

Victoria.—In this province argentiferous galena is known to occur at Sandhurst, St. Arnaud and other localities, but nowhere in large quantities.

Queensland.—In the Kangaroo hills are a number of silver deposits containing both galena and blende, which may become sources of lead supply.

South Australia.—Mines yielding both argentiferous galenas and zinc ores have been worked here, near Cape Jervis and at other points. The production has, however, not been very large. Between the years 1856 and 1881 there were produced and exported in ore about 7000 tons of lead, valued at $700,000. Between 1878 and 1881, 140 tons of zinc were exported.

Western Australia.—In the Champion Bay district, both lead and copper ores occur in gneisses and granite rocks, which are traversed by greenstones and other eruptives. The ores occur probably in lodes, but their conditions are obscure, and, though they present good prospects for the future, the developments have been slight. The principal mines worked have been the Huel Fortune, which produced between the years 1862 and 1868 over 2700 tons of lead; and the Geraldine, which yielded, from November, 1869, to December, 1870, 1820 tons of lead.

Tasmania.—In this country are the Zeehan and Dundas fields, on the western coast. The country rocks are Silurian slates. The Dundas field is traversed by several dikes of diorite. The ores occur in lodes, and are either fissures or segregated veins; some are along the contacts with the dikes. The ores are either galena or carbonates, with blende in a few places, in a gangue of siderite. The veins are very narrow [*8, p. 575*].

THE LEAD AND ZINC DEPOSITS OF SOUTH AMERICA.

In South America, the silver mines of Peru, Chili, Bolivia and Argentine republic yield argentiferous lead ores. The amount of lead contained is, however, comparatively small and entirely secondary. The total production of 1889 aggregated only about 6500 tons, and that of 1890 little more than 5000 tons.

Peru.—In Peru the largest operations are in Cerro Paso, at the Santa Rosa and other mines. Since the discovery of the deposit in 1630, it is estimated that $565,000,000 worth of silver had been produced [*167*]. Here, as in most Peruvian mines, the lead minerals are found at the lowest levels, and consist, principally, of lean, argentiferous galena. The country rocks are Jurassic and Cretaceous limestones, conglomerates, slates and sandstones, often metamorphosed and traversed by andesite. The ores are generally in quartzose lodes, which sometimes expand to great thicknesses. The minerals are distributed through the quartz in veins confined to certain zones called tajas, equivalent to our "bonanzas." Bed and pocket-like deposits are also recognized. The lead minerals are principally in calcareous rocks, and the best deposits are in Jurassic formations*. At Recuay, such rocks occur with intercalated melaphyres, which cut the metalliferous lodes. Two groups of lodes are recognized here—the principal ones running E.-W., the others N.-S. These both contain argentiferous galena (somewhat antimonial), argentiferous gray copper, iron and copper pyrites, blende, etc. In the N.-S. lodes the argentiferous copper ores are considered of first importance and the galenas are rejected. The lead ores contain, sometimes, as much as 70% of lead, and are high in silver.

Chili.—The Chilian deposits are also in lodes. These carry sulphides at lower levels in the unoxidized ores called *metales frios*. Such include argentiferous galena and blende, along with sulphides, sulpharsenides and sulphantimonides of iron, copper, nickel, cobalt and other metals. At Chanarcille, one of the historic and important mines, the lodes traverse Upper Jurassic limestones and intercalated layers of melaphyre and diabase. The latter are considered contemporaneous

*A brief, but excellent description of these mines, entitled Notes on the Topography and Geology of the Cerro de Pasco, Peru, by A. D. Hodges, is contained in Trans. A. I. M. E., vol. xvi, p. 729.

with the country rocks, and connect with transverse dikes. Three groups of lodes are recognized here, trending from N. to N. 45° E., and ranging from a few feet up to 30 feet in thickness. In traversing certain of the limestone strata the lodes are specially rich, and the wall rocks are also impregnated sometimes for a distance of 30 feet or more; in other strata the lodes are impoverished and there is no impregnation. The eruptives are only slightly or not at all impregnated, but contact deposits often occur along them. At Caracales are similar lodes in Jurassic rocks, which are traversed by quartz porphyries. The lodes are nearly vertical; vary from 2 feet to 14 feet in thickness, and are filled with a gangue of barite and calcite, with much iron oxide near the surface.

Bolivia.—In Bolivia are the famous deposits of Potosi, discovered in 1545. They have since yielded $1,200,000,000 worth of silver. The country rocks consist of a great dike or dome of quartz porphyry, surrounded by Silurian clay slates. Numerous lodes traverse the porphyry and enter the clay slates. The lodes are filled with a quartz gangue, in which the usual changes and groupings of metalliferous contents with depth are observed. An argentiferous gray copper ore is the principal object of mining.

At Orura are similar deposits in similar rocks. At Huanchaca are also a number important deposits.

At Pulacayo are metalliferous lodes in a decomposed trachyte. The principal one runs from E.–W., is between 3 feet to 10 feet thick, and has been exploited 3400 feet in length and over 1500 feet in depth. It is traversed by three fau'ts, which throw the lode from 6 to 200 feet. The upper levels are filled with barite and oxide, while the lower are more quartzose. Argentiferous gray copper is the principal metalliferous mineral, but with this ore are sulphides of lead, zinc, iron, copper, antimony, etc.

CENTRAL AMERICA.

In Central America, particularly in Honduras, are deposits of silver lead ores, some of which contain as much as 70 per cent of lead. Blende is also found with some of these, but is not mined. No production of lead ore is quoted from this country.

The Honduras mines are mostly in the states of Tegucigalpa and Choluteca. Some of these have been worked since early in the 16th century, and have yielded many million dollars worth of gold and silver.

The Aminas and California mines of the Los Angeles M. & S. Co. operate a nearly flat lode (dip 9° to 30° S.) resting on a quartzite conglomerate. The ore is argentiferous galena, with blende and pyrite, containing about 30% of lead [*231, p. 394*].

The Opteca mine is in the state of Comayagna. It was formerly of great importance, having been worked 200 years or more. The ore contained principally native silver, but also some sulphides.

The Yuscaran mines operate a true fissure vein, running N. of E. to S. of W. The ores consist largely of sulphides of silver, copper, zinc, lead and iron. The country rock is a variety of syenite, traversed by dikes of greenstone and other eruptives.

The Guadaloupe mine has produced ore, containing about 12 per cent of lead and some blende, from a lode running NW. to SE., traversing a conglomerate and, consisting, itself, of a white conglomerate impregnated with ore. At the Cuyal silver mines the lead contents of the ore ranged from 50 to 70 per cent.

THE LEAD AND ZINC DEPOSITS OF MEXICO.

The production of lead in Mexico, though large, has been entirely secondary to the production of silver, practically all of her lead ores being argentiferous. During the years 1883 to 1893, inclusive, there were produced over 330,000 tons of lead, beginning with about 16,000 tons in 1883, and reaching over 65,000 in 1893 [*195, vol. ii, p. 382*]. A large part of this, especially during all excepting the last three years, has been exported to the United States. The effects of these imports upon the markets of the United States are so considerable that the distribution and character of the deposits is of special interest here.

Zinc ores occur in many of the deposits, and have been mined and separated out at some localities, especially in the northeastern states; but of the amounts produced we have obtained only partial records. No spelter has been made.

The mines of Mexico were worked by the Aztecs before the conquest. From 1520 on they were worked by the Spaniards, while, for the past fifty years, the American interests have steadily increased. From the beginning to the present time, nearly 4,000 milion dollars' worth of silver and gold have been produced. Of this, probably over 90 per cent has been of silver.

The most important mining districts of early years were in the central portions of the republic. During late years developments in the northeast, in the states of Coahuila and Nuevo Leon, have been extensive, and have led to the establishment of large smelting works at Sierra Mojada, Monterey, San Louis Potosi, and Pedrisena. That of Sierra Mojada and one at Monterey are owned by Mexicans; others are controlled by American companies.

The early miners worked well-defined lodes, traversing, generally, limestones, marls or schists, associated with eruptives. These lodes have been exploited to depths of 2000 feet or more, and certain differences in composition and association are recognizable which are common to almost all. Fuchs and DeLaunay [*91, vol. ii, p. 816*] describe these zones downward as containing:

1. Native silver with oxide of iron and manganese in a quartz gangue;

2. Chlorides and bromides of silver and native silver;
3. Sulphide of silver with antimonides, constituting the *bonanzas*;
4. Sulph-antimonides of silver and red silver ores, with copper ores and blende, increasing with depth, till, between 1200 feet and 1500 feet, the filling is a mixture of blende, pyrite and quartz.

The Guanajuato District.—The mines of this district have been among the most famous, and were worked as early as 1558. They are declining in importance now. The great *Veta Madre* lode is the most important, though others are worked. The country rocks are Devonian clay slates and Triassic sandstone. The deposit, though in a true vein, follows the bedding, having a strike of 45° NW. and a dip of 45° SW. The thickness is, in places, over 400 feet, and of this more than 300 feet is sometimes ore-bearing. It has been exploited over nine miles along the strike. The gangue is principally quartz and calcite, enclosing fragments and masses of the country rock; with these are gypsum, spathic iron and fluorspar; barite is absent. The metalliferous minerals are silver and gold and various compounds of these, and also galena and blende; between the depths of 1200 and 1500 feet the proportion of galena is large.

Zacatecas and Fresnillo Districts.—These districts are respectively 150 and 200 miles northwest of the last. The lodes are similar and are also extensive. In Zacatecas the *Veta Grande* averages from 25 to 35 ft. in thickness and ranges up to 75 ft. The lodes are in a graywacke and are often sinuous and bifurcate. Galena and blende occur in the lower levels. At Fresnillo, some fifty or more veins, containing silver ores and galena and blende, are recognized either in graywacke or in Devonian clay slates. The Zacatecas deposits appear to be approaching exhaustion now.

Near Catorce, about 100 miles northeast of Zacatecas, are great lodes as much as 36 ft. thick, which have been exploited one and a half miles in length.

Durango.—In Durango are deposits at several localities yielding lead ores. The most important of these at present are the Velardina.

The Velardina mines are nine miles from Pedrisena. The ores are low grade, and could not be exploited until recent railway extensions were made. According to Mr. R. E. Chism: the ore deposits "occur at the contact of poryphyry and limestone, in well-defined bodies, which,

in some places, are 100 feet thick. Openings have been made on the vein, which dips vertically or at a steep angle, for a distance of 600 ft. The ore is a carbonate, high in lead and low grade in silver, with an access of iron over silica. The limestone country rock, which is not magnesian, furnishes the lime flux for smelting, and siliceous ores rich in silver are obtained in the immediate vicinity and in other parts of Durango; hence in all respects, except fuel, Velardena seems to be well adapted for silver-lead smelting. The mines are owned and operated by the Compania Minera de la Velardena, which has erected smelting works of six furnaces and employs about 750 men. The first furnace was blown in Nov. 1, 1893, and was followed by four more in December" [*195, vol. ii. p. 414*].

At Inde, in the northwestern portion of the state, are numerous small deposits in veins. These formerly yielded workable quantities of lead, but next to nothing during the past thirty years.*

Near Mapimi are old mines which formerly produced vast quantities of lead, but are now worked down to depths of 1200 ft., and have been abandoned for years.*

Pachuca.—Near Real del Monte, in this district, are a number of important silver mines, including the well-known Rosario. The rocks are porphyries and later eruptives. The lodes are always in the former, and are very numerous. The trend is generally E.-W., and the dip steep to the south. The gangue consists of quartz and a breccia of decomposed porphyry; calcite and barite are rare. The metalliferous minerals are principally native silver and stephanite; blende and pyrite are found, but are not common. The thickest lode is about 70 ft.; the longest has been traced a distance of nearly six miles, and it is thought that it may be a continuation of the *Veta Madre.* The mines of this district continue large producers up to the present time.

Zalapa.—A few miles northwest of Zalapa are the Tatitila and Zomlahuaca districts. The country rocks here are limestones, traversed by greenstones, porphyries and trachytes. The lodes, which are very numerous, are mostly in the limestones. Four groups of lodes are distinguishable, one of which is characterized by argentiferous galena, in a gangue of quartz and calcite. The lodes vary, as a rule, from 3 feet to 6 feet in thickness. At La Conception mine, the ore body is massive, and contains auriferous quartz, with lead, silver and copper ores.

*Private communication of Mr. John N. Judson.

Sultepec.—The mines near this place, about 60 miles southwest of the City of Mexico, operate lodes containing principally argentiferous galena and copper and iron pyrites as metalliferous minerals. These are lean in silver. The deposits were worked before the conquest.

At Malacate, near by, are a number of lodes containing galena and blende, along with other minerals.

Morelos.—The San Francisco mines of this district operate a true vein about 4 feet thick. The ore is found in pockets in a quartz gangue. Argentiferous galena preponderates in one part of the deposit, while elsewhere, argentiferous copper ores take the place of the lead.

In northwestern Mexico, in Sonora and Chihuahua, are a number of important silver mines, but the lead contents of the deposits are comparatively unimportant. Near Parral, Mr. Judson* writes that judging from the dump piles of mines there, a good deal of smelting ore must have been raised there formerly.

Coahuila.—In this, the northeastmost state of Mexico, are at present the most important lead-producing mines.

The Sierra Mojada mines are located near the western border line of the state, about 100 miles south of the Rio del Norte. The deposits were known to the early Spaniards, but were, apparently, abandoned and were not rediscovered until 1878. In 1893 the daily shipments of ore were as much as 500 tons, and up to Oct. 1st, 1892, the output was 500,000 tons for that year [*87, p. 151*]. According to Mr. R. E. Chism [*44, p. 542*] and Mr. Fechet, the country rocks are magnesian limestones, as much as 2000 ft. thick, of probable Cretaceous age, striking E.-W. and dipping 25° to 30° N. Some beds of calcareous sandstones are also included, and one stratum of conglomerate occurs near the base.

The ore deposits are confined to the northern slope of the mountain range. They occur in strata of altered limestone, principally in the form of great bedded veins or chambers. They appear to be confined to a certain horizon and dip with the strata. They occur about one-third the way up the mountain, and are traceable at this altitude a distance of about four miles. The metalliferous minerals consist principally of silver compounds, of galena, cerussite, anglesite, with which is found native sulphur, and copper carbonate. Much limonite, hematite and manganese are, in places, associated with the lead and

*Private communication.

copper ores. According to Mr. Fechet, the lead contents average about 30 per cent, and the silver about 35 ounces.

From the following table of productions and compositions, kindly obtained by Mr. Judson from Mr. Paul La Monte, government assayer at Sierra Mojada, it appears that this estimate is too high, at least so far as present productions are concerned:

AMOUNT OF ORE EXTRACTED FROM THE SIERRA MOJADA MINES,
From May 1, 1893, to April 30, 1894.

	Tons ore.	Silver oz. per ton.	Copper per cent.	Lead per cent.	Lead contents, tons.
San Salvador	100,335	17.62	....	25.0	25,084
San Jose	18,671	33 42	....	22.0	4,108
"	17,070	48.61	3.4	....	....
Esmeralda	2,622	18.84	....	24.6	645
Providencia	3,934	18.24	....	20.6	810
Fortuna	14,534	18.84	....	23.9	3,386
"	5,772	58.33	4.0	....	....
Encantada	8,409	10.33	....	32.1	2,699
Parrina	883	10.33	....	32.0	283
Ste Madre de los Angeles	335	15.19	Dry	....	....
Explorador	598	48.61	4.1	....	....

Total lead ore 149,388 tons, containing 37,015 tons lead.
Total copper ore 23,440 " 888 " copper.

The gangues are calcite, "felspar" and barite. The deepest work in 1893 was about 500 ft. The most important mines at present are the San Salvador, the San Jose and the Fatima; in the past, the Encantada and the Esmeralda have been large producers. Mr. Fechet estimated the ore reserves in sight sufficient to last ten years.

In the Santa Rosa and Monclova mining districts are a number of deposits, which are classed as lodes traversing Lower Carboniferous limestones. They contain argentiferous galena and cerussite, along with native silver [*201, p. 388*]. They are now worked to water level.

Near Cuatro Cienegas, Mr. Judson refers to two groups of mines of which the ore was high in lead, but low in silver, which have been

worked a little. All along the mountains from Santa Rosa southeastward are scattered small mines which were worked during our civil war and at other times when trade conditions were particularly favorable. They are now mostly down to the level of heavy flow of water.

Nueva Leon.—One of the foremost mines of this state is the Vallecillo, north of Monterey. The deposit appears to have been worked by the Spaniards, but was long abandoned, and not again continuously worked until taken hold of by an American company in 1851. Mr. Chism has described the mine with great completeness [*43, p. 351*]. According to his description the country rock is a shaly, non-fossiliferous limestone, in a nearly horizontal attitude and undisturbed by faults or fractures. The deposit is a lode or a true fissure vein running N. 40° E., and dipping 56° NW. The average thickness is about 3 ft., and the pay-streak varies from 6 ins. to 18 ins. The gangue minerals are calcite, feldspar and fluorspar, with no considerable amounts of barite; with these are galena, blende, and copper and iron pyrites, represented by oxides and carbonates near the surface. These are irregularly banded, and lenses of galena and blende alternate with each other, in the lode, though overlapping. Mining in 1884 had extended to depths of 450 ft. About a third of the yield of metalliferous minerals was blende, and, at that time, it had accumulated to great bulk, awaiting shipment.

Near Villadama, Frazer [*90, p. 537*] describes certain other limited pocket-like deposits in a limestone country rock, which contain small quantities of lead and silver.

Tamaulipas.—In this state, in the southern portion, are deposits which, Mr. Judson writes, are reported to yield promise of becoming productive. The San Carlos mine operated such a one. Up to 1885 they had not been worked for years.

LEAD AND ZINC DEPOSITS OF THE DOMINION OF CANADA.

So much of the great territory of British America remains yet comparatively unexplored, that it is impossible to describe with fullness the extent and nature of its mineral deposits. Up to the present time, however, the only important discoveries of ore which may develop into sources of large lead supply are in British Columbia, in what is known as the West Kootenay district. Here are argentiferous lead ores in many respects similar to those of the states of Idaho and Montana, immediately south. Other deposits containing silver-bearing galena have been worked elsewhere in the dominion, but they are not to be regarded as sources of lead. Some of these latter contain also considerable quantities of blende, but no deposits are worked for zinc ore.

West Kootenay District.—The known deposits of this district are at somewhat widely separated localities, between Illicilliwaet on the north and Nelson on the south. The most important are those of Nelson, Hot Spring, Casloslocan, Golden and Illicilliwaet [*29. 60, 61, 62*]. Comparatively small amounts of ore have been produced so far, however; transportation being difficult and smelting works not having yet been erected in the region, though such ores have been treated at Vancouver. Tariff rates into the United States have prevented the shipment of the ores to the works of Idaho or Montana. During 1888 and 1889 Canadian reports give a production of only 420 tons [*63, p. 62*]. The district is considered by Canadian geologists to be one of great promise, and, according to one statement, a production of as much as 250,000 tons of ore can be easily attained.

The country rocks are Archean granites and schists, overlain by Paleozoic schists, marbles, limestones, quartzite, slates and argillites. The deposits are almost entirely in the latter.

The Illicilliwaet ores occur in lodes, running principally N.–S., but also intersected by cross lodes. They occur in black slates and limestones of probably Cambro-Silurian age. The gangues are quartz calcite and earthy matter, containing galena, blende and iron pyrite. The lead contents vary from 40 to 70 per cent.

At the Hot Spring mines, on the west side of Lake Kootenay, are lodes running generally N.–S., nearly or exactly parallel with the strike

of the country rocks, which are mainly schists and limestones. Some of these follow the stratification, while others are across it, and the character of the ore-body varies noticeably with the enclosing rock. The gagues are principally quartz and calcite. The ore is largely argentiferous galena, oxidized to a rusty carbonate in places. The lodes in the schists are a few feet thick and are quite regular; in the limestone they are very irregular—the ores sometimes impregnating that rock, sometimes occurring in large masses or "chimneys," and in great part oxidized. A large number of claims are located here.

The Hendryx deposits, nearly opposite Hot Springs, on the east side of the lake, are very large, though of lower grade. The rocks are schists, quartzites and marbles. The ores consist of iron and copper pyrites, galena and blende, in a quartzose gangue, which is sometimes in cavernous bodies. Masses of pure galena are found in places.

The Todd Mountain deposits, near Nelson, are somewhat similar but contain only traces of lead ore.

North Shore of Lake Superior [*64, 65, 66*].—Along the shore of Thunder bay and on adjacent islands, a number of silver deposits have been worked which contain both blende and galena as accessory minerals. The rocks belong to the Copper-bearing series, and consist of dolomites, cherts, sandstones, conglomerates, argillites, etc., traversed by eruptives. These are crossed by lodes carrying blende, galena, copper and silver ores, in gangues of quartz or calcite, generally brecciated. The Shuniah lode, from 2 ft. to 23 ft. thick, running E.–W., consists of a gangue of quartz near the surface and of calcite lower down, carrying blende and a little galena. The Silver Islet lode follows a fault plane; it also contains some blende and galena in a gangue consisting largely of calcite.

In the province of Quebec [*76 p. 77*], limited deposits of argentiferous galena occur on Du Loup river. They consist of quartzose veins a foot, more or less, thick, carrying both blende and galena. They occur in Cambrian slates and sandstone, which were traversed by diorite dikes. In the Pontiac country, on the Ottawa and elsewhere, small quantities of such galena have also been found.

In the American provinces, small quantities of argentiferous galena have been discovered on the Tombique and Hammond rivers and at Musquash harbor, all in southern New Brunswick; in Nova Scotia on Gay's river and near Guysborough [*64, pp. 275, 351, 640*] [*35, p. 25*].

MASSACHUSETTS.

Noteworthy deposits of lead ore occur at two localities in the state. The first and longest known is in the central portion, in the vicinity of the Connecticut river. The second, of comparatively recent development, is at Newburyport in the extreme northeastern corner of the state. With the first deposit some zinc blende is associated. At Worcester, and at Sterling, a few miles north of that town, small amounts of galena have been found associated with arsenical iron ore and carbonate of iron. At the latter place sphalerite of a cherry-red color also occurs. The existence of galena and some blende in a fetid limestone in West Springfield is also noted [*105, p. 448*].

The deposits of the Connecticut valley were described by Hitchcock in his first report on the Geology of Massachusetts [*105. pp. 1 99–2*]. They occur principally in the vicinity of Southampton. He states that as many as 14 noteworthy veins occur here, in mica slate or granite. The ore is almost exclusively galena.

Southampton.—The most important of these deposits was at Southampton. Work was begun here in 1765, but was suspended by the Revolutionary war, and not resumed until 1809. The works were visited by Prof. Silliman in 1810 [*234, p. 390*]. The vein here is 6 to 8 feet wide, traversing mica slate and granite. The gangue is a mixture of quartz, and barite through which the ore occurred in masses from one-half inch to one foot in diameter. Shafts have been sunk in this vein to a depth of from 40 to 50 feet, and a tunnel has been driven in to cut it to a distance of 900 feet. This was, however, abandoned just before the vein was reached, largely because of the depression in the price of lead at the time. Hitchcock states that doubtless immense quantities of the ore may be obtained here. Along with the galena some carbonate, sulphate, molybdate, chloride and phosphate of lead were recognized. Also blende, chalcopyrite and fluorspar.

At Northhampton a similar vein is exposed several feet wide. The walls are mica slate, the gangue radiated quartz. Yellow blende occurs here in great quantity. Similar veins are recorded in Westhampton; in Williamsburg, associated with oxides of manganese; in Goshen; in Whately, where three veins were recognized consisting of a quartz gangue with galena; in Hatfield, where the gangue was principally barite and the vein from one to four feet wide, and in Russell, where the ore consists of galena, blende and chalcopyrite. In Leve-

rett two veins were discovered, one traversing granite and containing galena in barite; the other containing galena, chalcopyrite and some blende and quartz.

The Newburyport Deposit.—At Newburyport a vein of argentiferous galena was discovered early in the year 1874. The first pit was put down in May of that year, and fragments of galena with gray copper, siderite and quartz were taken out, which indicated a decided vein structure in the deposit [*189, p. 442*]. Later in the same year several parallel crevices were uncovered running in a nearly eastward direction, or a little north of that course. These were within a few feet of each other. One of these was six inches thick at the surface. On this the Chipman shaft was sunk. At a depth of 10 feet, the deposit widened to a thickness of three feet, and at a depth of 22 feet, the galena vein measured six feet thick. Lower down the thickness varied from 10 to 16 inches. Assays of this ore showed it to be rich in silver. One assay of a drill sample through the thick mass of the ore yielded about $70 worth of lead, $73 worth of silver, and $11 worth of gold to the ton of 2240 pounds. A level at a depth of 100 feet was driven. This shaft was well equipped with hoisting engine, cage cars and pump, and in September, 1875, had a regular yielding of about seven tons per day.

Concerning the final results, Prof. Richards writes * as follows:

"At about 60 ft. down the lower limit of the ore was reached: that is, the deposit that had averaged one foot thick toward the east end and six inches thick at the west end, of good rich mineral in a length of 200 ft., rapidly gave place to a vein of quartz dotted with a little galena, and so went on to a depth of 225 feet, when the courage of the owners gave out.

"There was another vein farther north and east, seemingly about parallel to this, which contained a great deal of arsenopyrite; in fact that and quartz composed the vein.

"Another vein south of the Merrimac vein had a great deal of zinc blende in it, and the siderite was pretty much wanting."†

*Private communication June 16, 1893.

† For further references on Massachusetts deposits, see appendix C [*106, vol. iii, pt. v, p. 34; also 74, 114. 152, 189, 190, 215*].

MASSACHUSETTS.

Noteworthy deposits of lead ore occur at two localities in the state. The first and longest known is in the central portion, in the vicinity of the Connecticut river. The second, of comparatively recent development, is at Newburyport in the extreme northeastern corner of the state. With the first deposit some zinc blende is associated. At Worcester, and at Sterling, a few miles north of that town, small amounts of galena have been found associated with arsenical iron ore and carbonate of iron. At the latter place sphalerite of a cherry-red color also occurs. The existence of galena and some blende in a fetid limestone in West Springfield is also noted [*105, p. 448*].

The deposits of the Connecticut valley were described by Hitchcock in his first report on the Geology of Massachusetts [*105. pp. 1 99-2*]. They occur principally in the vicinity of Southampton. He states that as many as 14 noteworthy veins occur here, in mica slate or granite. The ore is almost exclusively galena.

Southampton.—The most important of these deposits was at Southampton. Work was begun here in 1765, but was suspended by the Revolutionary war, and not resumed until 1809. The works were visited by Prof. Silliman in 1810 [*234, p. 390*]. The vein here is 6 to 8 feet wide, traversing mica slate and granite. The gangue is a mixture of quartz, and barite through which the ore occurred in masses from one-half inch to one foot in diameter. Shafts have been sunk in this vein to a depth of from 40 to 50 feet, and a tunnel has been driven in to cut it to a distance of 900 feet. This was, however, abandoned just before the vein was reached, largely because of the depression in the price of lead at the time. Hitchcock states that doubtless immense quantities of the ore may be obtained here. Along with the galena some carbonate, sulphate, molybdate, chloride and phosphate of lead were recognized. Also blende, chalcopyrite and fluorspar.

At Northhampton a similar vein is exposed several feet wide. The walls are mica slate, the gangue radiated quartz. Yellow blende occurs here in great quantity. Similar veins are recorded in Westhampton; in Williamsburg, associated with oxides of manganese; in Goshen; in Whately, where three veins were recognized consisting of a quartz gangue with galena; in Hatfield, where the gangue was principally barite and the vein from one to four feet wide, and in Russell, where the ore consists of galena, blende and chalcopyrite. In Leve-

rett two veins were discovered, one traversing granite and containing galena in barite; the other containing galena, chalcopyrite and some blende and quartz.

The Newburyport Deposit.—At Newburyport a vein of argentiferous galena was discovered early in the year 1874. The first pit was put down in May of that year, and fragments of galena with gray copper, siderite and quartz were taken out, which indicated a decided vein structure in the deposit [*189, p. 442*]. Later in the same year several parallel crevices were uncovered running in a nearly eastward direction, or a little north of that course. These were within a few feet of each other. One of these was six inches thick at the surface. On this the Chipman shaft was sunk. At a depth of 10 feet, the deposit widened to a thickness of three feet, and at a depth of 22 feet, the galena vein measured six feet thick. Lower down the thickness varied from 10 to 16 inches. Assays of this ore showed it to be rich in silver. One assay of a drill sample through the thick mass of the ore yielded about $70 worth of lead, $73 worth of silver, and $11 worth of gold to the ton of 2240 pounds. A level at a depth of 100 feet was driven. This shaft was well equipped with hoisting engine, cage cars and pump, and in September, 1875, had a regular yielding of about seven tons per day.

Concerning the final results, Prof. Richards writes* as follows:

"At about 60 ft. down the lower limit of the ore was reached: that is, the deposit that had averaged one foot thick toward the east end and six inches thick at the west end, of good rich mineral in a length of 200 ft., rapidly gave place to a vein of quartz dotted with a little galena, and so went on to a depth of 225 feet, when the courage of the owners gave out.

"There was another vein farther north and east, seemingly about parallel to this, which contained a great deal of arsenopyrite; in fact that and quartz composed the vein.

"Another vein south of the Merrimac vein had a great deal of zinc blende in it, and the siderite was pretty much wanting."†

*Private communication June 16, 1893.

† For further references on Massachusetts deposits, see appendix C [*106, vol. iii, pt. v, p. 34; also 74, 114. 152, 189, 190, 215*].

CONNECTICUT.

Galena is found at a number of localities in the state, but has been wrought at only a few points and on a small scale.

The most important deposit seems to be that at Middletown. This is described as galena in a thin seam of quartz, 10 to 20 inches thick, traversing mica slate. With the galena are zinc blende and iron pyrite. These minerals form, however, only a small proportion of the vein [*50, p. 52*]. According to Whitney, work was probably begun here as early as the latter part of the 17th century. The course of the vein is about N. 50 E., and the dip about 45° N. W. Up to 1854 a shaft had been sunk to a depth of 120 feet, and several levels were driven. Parts of the lode proved wide and rich, other parts poor.

Near Brookfield, some little lead ore has been found in limestone. In Monroe, galena in small quantities is found disseminated through a lode of quartz.

NEW YORK.

In the State of New York there are a number of deposits of lead ore which were considered at one time worthy of development. These are situated in three sections of the state: i. e., in St. Lawrence county in the northern part, in Washington, Rensselaer, Columbia and Dutchess counties in the eastern part, between the Hudson river and the state line; and in Ulster, Sullivan and Orange counties in the southeastern corner.

In Ulster county the ore occurs in a series of vertical fissures which traverse Silurian rocks (grit and sandstone). At Ellenville a mine was opened many years ago on one of these fissures, and was quite extensively worked. They are nearly vertical and run transversely to the stratification. The veins are quite narrow in many places, but open out elsewhere to large chambers five feet or more wide. In these chambers copper and lead ores are found, associated with crystals of quartz, all enclosed in yellow clay. The ore courses in the fissures follow pretty nearly the lines of stratification. Whitney calls these "great gash veins," and thinks they are probably confined to the grit beds [*234, p. 402*].

The Ellenville mine was worked first in 1820, and later again, but with little success. Several veins near here were worked about 1854. Two Scotch hearths were erected for smelting these ores, which yielded

70 per cent of lead in the furnace. Up to 1854 about $33,000 worth of lead and $3000 worth of copper had been produced.

Near Redbridge, in this same county, a similar deposit of lead ore occurs, which was opened and worked in 1837. The gangue here is largely siliceous, frequently in the form of large quartz crystals; with these are associated masses of galena, blende, and copper and iron pyrite.

At Wurtzboro, in Sullivan county, another similar deposit of lead was worked for many years. Near Guymard, in Orange county, a rich vein of lead ore was found about 1858. Mining was still being done there in 1868, and a large quantity of lead had been taken out [*52, p. 147*]. Dr. Cook states that this last discovery caused much excitement, and quite extensive search was made all along the western slope of the Kittatinny mountains. Small quantities of ore were found at several places, and it was determined that these were associated in some way with vertical quartz veins which crossed the mountains at right angles to the strike.

Prof. I. C. White, writing in 1881 [*232, p. 151*], states that genuine fissure veins occur in the Medina sandstone in the Shawangunk mountains, which probably extend down through the Oneida conglomerate. One of these was from three to four feet wide, running N. 70° E. One of the shafts in the vicinity of Guymard had been carried down to a depth of 400 feet. Prof. Lesley adds, in a foot note here, that it is possible that these lead veins have been created as recently as Cretaceous times, and he suggests that they may have risen from the Trenton limestone, which would show that this part of the earth crust had been profoundly fissured.

In Columbia county, the Ancram or Livingston mines were the most important. Here the lode or vein is found in argillaceous, metamorphosed slates, close to a crystalline limestone. The gangue is quartz, and the ores are galena, blende and copper pyrite. The vein is only about 4 inches thick. Its course is diagonally across the statification, and its dip is nearly vertical. The mine was worked in the early half of the century, and work was resumed about the year 1853. According to Whitney [*234, p. 395*], Prof. Beck states that this is not a true vein, but is rather a collection of strings and bunches of ore parallel to the stratification, with no well-defined walls. Though extensively operated, it has never proved remunerative.

Near Northeast, in Dutchess county, a little lead ore has been found. It was worked as early as 1740, and small amounts were shipped abroad. Attempts to obtain lead here were also made during the Revolutionary war. The quantity is too small, however, to admit of profitable development.

In Herkimer, Montgomery and Lewis counties, specimens of lead in Lower Silurian strata have been found.

In St. Lawrence county are perhaps the most considerable deposits of lead in the state. They occur in the western corner of the county, near Rossie, in Archean gneiss. They were worked at intervals during the first half of the century, from the year 1835 on. The most important deposit at Rossie is probably what was known as the Coal Hill vein. Whitney quotes several descriptions of the deposit [*234, pp. 382–387*]. A number of veins occur in a group here, of which the Coal Hill vein is the largest. Its average width is about two feet, but it reaches four feet in places. It is nearly vertical, with a SSE. course. It had an exposed length in 1837 of 450 feet. The gangue is principally calcite, in which the lead ore occurs. This last is somewhat irregularly distributed, and occupies from two to eighteen inches of the width of the vein. The ore is remarkably free from iron, copper or zinc sulphides; it carries a trace of silver. Operations were conducted in the Coal Hill vein in 1837 to 1839, and again in 1852. During the first period, about 1800 tons of lead were smelted. The Victoria Lead Co. operated a similar parallel vein during 1836 to '37, from which 524 tons of lead were produced. This vein also was reopened in 1852. These deposits are noted for the beautiful crystals of galena and calcite which they furnish.

During the past twenty-five years, the deposits of New York have received little notice, and have practically been non-producers of lead. Beyond the figures given above, we are unable to state what New York's production of lead has been.

PENNSYLVANIA.

The discoveries of zinc and lead ores made in Pennsylvania many years ago led to the anticipation that large deposits of these minerals might be developed in the state. The results have not, however, proved equal to these expectations. Only one zinc deposit of magnitude has been operated with profit, and little lead has been produced since the operations of the Chester county mines in the early fifties.

Friedensville.—The Saucon valley zinc deposits in Lehigh county are by far the most prominent. They are located only a few miles south of Bethlehem, and the zinc works at that place were supplied from these Friedensville mines. According to Mr. H. S. Drinker [*70, p. 67*], zinc was first discovered here in 1845 by Prof. W. T. Roepper. Some work was done soon after the discovery, and mining on an extensive scale was begun in 1853 by the Pennsylvania & Lehigh Zinc Co. At the same time smelting furnaces and a plant for the manufacture of zinc oxides were erected at Bethlehem by the same company [*234, p. 351*].

Three openings have been made in these deposits by the Lehigh and other companies, known respectively as the Ueberoth, Hartman and Saucon mines. They are within a half mile of each other. These have been described in some detail by Mr. F. L. Clerc [*240, p. 361 et seq*]. They are essentially large open cuts. The first named is by far the largest. It was worked continuously from 1853 to 1876 and extends to a depth of 250 feet on the slope of the bed and more than 1000 feet along the strike. Mammoth pumping engines were erected here to drain the mine. An excessive amount of water was encountered, which was ultimately one of the causes of cessation of work. The Hartman mine is a smaller opening and extends to a depth of 150 feet. Saucon mine reaches a depth of 200 feet. These deposits were almost uninterruptedly worked until 1878. In 1882 Mr. Clerc wrote that they were producing but little ore.

The country rock is here a dolomitic limestone of Lower Silurian age. The strata are nearly vertical in places, and the rock appears much disturbed and fractured. The strike is from S. W. to N. E. The mode of the occurrence of the ore is somewhat peculiar, and is differently described by various authors; and the source of the ore is also attributed to a different origin. Thus Rogers [*193, vol. i, p. 236*] speaks of the ore as "injected" into the limestone, and speaks of much injected quartz associated with that rock. He describes the veins of ore as coinciding in direction with the axis of a syncline along which there is possibly some faulting. Mr. Frederick Prime [*175, p. 239*] states that the limestone appears broken and cracked and the interstices are filled with ore, giving the appearance of a breccia. The ore extends vertically 30 or 40 feet across the strata, in some places, while elsewhere the ore bed is only 10 to 20 feet thick. Mr. Drinker states that the ore occurs in vertical veins, of which the most important run

in the east and west direction. Mr. Clerc describes the ore at the Ueberoth mine as following crevices between blocks of limestone, the crevices being both parallel to the vein and perpendicular to it. They continue undiminished in thickness down to the limit of depth reached by the workings. He recognizes six parallel crevices and as many crossings. At the intersections, bunches of ore 20 to 60 feet in thickness were found. The deposits at the Saucon mine he describes as a large chimney or chute of irregular cross section, but of lenticular shape; the longer axis 60 feet, the transverse axis 30 feet. The pitch was S. about 30°. He speaks of all these ore bodies as three deposits of blende and calamine in nearly parallel chimneys.

The ore proper consists of bluish blende associated with pyrite; smithsonite and calamine were found near the surface. It is remarkably free from lead, arsenic and antimony, which commends it for use in the manufacture of spelter. A little galena is found in large crystals.

Full figures of the production of this mine are not obtainable. Up to the end of 1876 the Ueberoth mine is estimated to have produced 300,000 tons of ore. In 1872 these mines were producing about 20,000 tons per annum, and during the preceding years had yielded at the rate of about 12,000 to 15,000 tons per year.

Blair County.—Another group of deposits which have been quite extensively developed is in Blair county, in Sinking valley near Birmingham. Both lead and zinc ores are found here. The operations have not, however, proved remunerative. The deposits occur in dolomitic limestone of Trenton age, near the center and terminus of one of those inverted canoe-shaped valleys of anticlinal structure which are so common in Pennsylvania.

The deposits were worked to a slight extent during the revolution, in 1778. Reduction works were erected and lead was smelted and shipped down the river. They were again operated about 1795. The principal operations have been in recent years, however, by the Keystone company, who began operations in 1864, and suspended work in 1870. During this period over 2000 tons of ore were produced. Large works were erected here, which utilized this and other ore for the manufacture of zinc oxide. In 1875 a small amount of additional development and drilling was done.

The ore occurs at the east end of the valley, near Birmingham, in fissures along the anticlinal axis, parallel to the stratification, the

course being S. 65° W. The fissures vary in width from thin threads to spacious chambers; in length, however, they seem to be very limited, the longest drift in the southwestern direction being 160 feet. Immediately east, as well as west, of these mines, deposits are not found. Mr. Franklin Platt, whose descriptions we make use of here [*170, p. 25*, *et seq.*], regards these fissures as probably extending to indefinite depths.

West of the Birmingham openings is a barren interval of some five miles. Beyond this, in the extreme western end of the valley, fissures are again found in the upper layers of the Trenton. They are here, however, very generally transverse to the stratification, are vertical, are scattered across the valley and are quite thin, few exceeding six inches and the maximum reported not being over two feet thick. A large number of pits and shallow shafts have been sunk here, but no extensive workings.

Mr. Platt thinks that these fissures are probably due to the movement which caused the general flexing of the rocks, and those at the west end of the valley are perhaps due to shrinkage. Thin strata of galena and blende are frequently found in the country rock at distances from the large deposits.

The ores are zinc and lead sulphides, calamine and some pyrite. The blende predominates, and the ore averages about 30 per cent metallic zinc. The gangue is dolomite, barite, ferruginous clay and sometimes calcite.

The source of this ore, it is suggested, is the disseminated mineral in the country rock. This may have been dissolved and re-precipitated in the crevices formed by the earth movements. Similarity between these deposits and those of the Mississippi valleys make them of special interest here. It is probable that they have a similar origin.

Lancaster County.—In Lancaster county, near Landisville, is the Bamford zinc mine. The deposit was discovered in 1845, and was worked for the production of white oxide some 35 or 40 years ago. It was purchased and reopened for extensive work in 1873.

According to Mr. E. G. Spillsbury [*211, p. 198*], the superintendent, the ores are found in two parallel bedded deposits in Lower Silurian limestone, close to the contact of this limestone with shale. These deposits are parallel to the strike and dip of the rocks, and have a course of N. 74° E., and a dip of 72° NW. The limestone hanging wall is brecciated and decomposed, is full of seams and cavities, and

even caves, which are as much as 20 feet long and 6 feet high. These cavities are generally filled with a dark and sandy loam. Along the foot-wall the ore is somewhat interlaminated with that rock, which is less siliceous, compact and dark blue.

The ores are sulphide of zinc and lead changed to carbonates near the surface. The gangue is limestone. The galena contains silver in amounts varying from $2 to $2000 to the ton. The blende is a variety known as rosin blende, containing a small amount of cadmium. The ore averages from 17 to 18 per cent of blende. The galena is found in bunches or strings near the hanging wall, while the blende impregnates the whole bed.

This deposit has been traced a half mile, and indications of its extent beyond this exist, but they have not been proved. In the southern vein the richest ore was between the depths of 55 and 75 feet. At 110 feet this vein had little or no ore. The northern vein is perfectly barren below 50 feet. The operations here did not prove remunerative.

Northumberland County.—In this county, a few miles below Sunbury, on the Susquehanna river, a considerable deposit of lead and zinc ore has been found. It occurs, according to Prof. I. C. White [*231, p.99*], in what is known as the Bassard limestone of Silurian age, near the base of the Lower Helderberg. It was discovered about 40 years ago, and some work was done then. Systematic development was not begun, however, until 1882. The deposit is on the crest of an anticlinal arch, and follows the strike of the beds in an east and west direction. The ore occurs in patches and pockets, associated with clay and detrital material. It consists chiefly of sulphides of lead and zinc; in composition it averages 20% of lead and 32% of zinc.

In Columbia county, between Lime Ridge and Espy, this same formation contains a little lead and zinc ore, and some prospecting has been engaged in.

Chester County.—A few miles south of Phenixville, along Pickering creek, are a series of ore deposits of great geologic interest. A number of mines were operated here about 40 years ago, and considerable quantities of lead and copper were taken out. Since that time, however, little work has been done. According to Whitney [*234, p. 396*], the Chester Mining company took possession in 1850, and, at that time, a drift 837 feet long had already been driven and about 20 tons of lead ore and some copper had been produced. A furnace was erected in 1851, and about 90,000 pounds of lead were produced that

year. One of the principal mines of this group was the Whately. This, according to Rogers [*193, vol. i, p. 701*], was opened by a drift 3072 feet long. Several other mines which were ore producers were opened in this neighborhood.

The ore occurs in veins near the contact between Archean gneiss and Mesozoic red sandstone and shale. These veins may be on one side or the other of the contact, and, sometimes, they extend across it. They have generally a N.-E. course, though they vary somewhat in direction. The rock is much decomposed near the veins. Lead ore is found chiefly in the veins of the gneiss, while the red shale veins are characterized by copper. Zinc ore is found in both, but perhaps more abundantly in the shale. The surface ore is principally phosphate of lead associated with the sulphates and carbonates. Galena is found at depths. Many other compounds of lead, zinc, copper and iron are recognized.

Rogers expressed the opinion that these ores are derived from deep sources, and that they were injected into the veins by igneous action. In confirmation of this, he adduces the presence of pure sulphur enclosed in galena. Further, he attributes the existence of galena at depths, and carbonates and phosphates near the surface, to the fact that galena condenses at a higher temperature than do the latter two compounds—a somewhat peculiar explanation of the results of atmospheric weathering.

The rocks here are traversed by dikes, which are later than the overlying Mesozoic beds. The veins of ore are found to traverse and fault these dikes, and are hence older than the latter and are probably of pre-Cretaceous age.

Figures of production of lead and zinc in Pennsylvania seem never to have been compiled. Special effort was made to obtain them, through application to the state departments, but without success. From the figures already given of the Ueberoth mine, it seems probable that the total production of zinc ore in the state is somewhere between half a million and one million tons. The production of lead ore must be considerably less.

NEW JERSEY.

One of the largest zinc ore deposits in the country occurs in Sussex county, New Jersey. Mining of this ore was started as early as the year 1850, and at that time these were the only deposits worked

for zinc on the American continent [*234, p. 348*]. Lead as galena or in other compounds is not found in New Jersey in sufficient quantities to work.

The important zinc-producing localities of the State are at Franklin furnace and at Sterling Hill, both in Sussex county. The deposits are about two miles apart.

Sterling Hill.—The ore crops out on the southeastern slope of a ridge to a height of about 100 feet. Prof. Cook describes the veins as conformable to the stratification of the white crystalline limestones in which they occur.* The dip is steep to the southeast [*52, p. 669*]. The thickness varies from 4 to 20 feet. The gangue is calcite, replaced in part by carbonate of manganese. Zinc minerals are disseminated through this, but not uniformly. The principal deposit of ore is in the middle of the gangue rock and occurs in two layers or sheets parallel to the walls. The upper of these sheets consists of franklinite, a compound of oxides of iron and maganese with only about 24 per cent of zinc oxide. The lowermost of these sheets is principally the red oxide, carrying about 80 per cent of metallic zinc. The silicate, willemite (73 per cent zinc oxide), is also associated with these ores. At one mine considerable quantities of the hydro-silicate, calamine, were also found, which is considered a secondary product derived from the willemite and red oxide.

Mine Hill.—In the Mine Hill mine at Franklin furnace the ores are about the same, though the willemite is more abundant. The red oxide is here comparatively scarce and occurs in grains and blotches. The ore in one part of the deposit here is also in two layers, though elsewhere this division is not so plain. The gangue is the same as at Sterling Hill, and the country rock is similar white, crystalline limestone, with which the vein is conformable. The vein occurs here quite close to (within 10 to 20 feet of) the underlying Archean gneiss. The outcrop is about 2000 feet long, and, at its western end, bends abruptly to the east and extends thence about 800 feet in that direction. An excellent description of this deposit has recently been given by Mr. Nason [*153*]. According to this the ore body is interbedded in the limestone, and lies in the shape of a syncline or trough, pitching steeply to the northeast. At the southwestern end the bottom of the trough reaches the surface. About 700 feet northeast of this end a

* The age of these limestones has been a question of much dispute. They have been considered Archean, Cambrian and Silurian. In the last paper on the subject by Mr. Frank L. Nason they are called Cambrian [*257*].

trap-dike crosses the basin at right angles. Dikes of granite also penetrate the limestone, but it is doubtful if they enter the granite. On the south and east sides of the basin the sheet of ore seems to be bent back upon itself in the form of a compressed anticline. The thickness at the bottom of the trough reaches as much as 100 feet; on the sides it varies from 25 to 50 feet. From the results of recent drillings Mr. Nason estimates that there is here, probably, a body of ore 3500 feet long, 800 feet wide, averaging at least 25 feet thick.

A number of large openings have been made at both of these localities, principally by the New Jersey Zinc company, which was organized in 1858, and later by the Lehigh Zinc and Iron company. The two deposits have the same trend, and the northern one is in the extension of the southern; but in the intervening two miles the vein is not found. At these mines beautiful crystals of various zinc compounds occur, along with many other interesting minerals. Among these we may mention fowlerite, fluorite, sussexite and jeffersonite.

An average sample of the Mine Hill ore is stated to contain 36 per cent ZnO, 22 per cent Fe, and 11 per cent Mn. Owing to the low zinc contents and to the large amounts of iron and manganese present, this ore is not used for the manufacture of spelter, but for zinc white. It has been impracticable to separate these minerals mechanically. A high grade of spelter is made from the Sterling Hill ores, however [*240*, *p. 361*].

Warren County.—Near Oxford furnace, in Warren county, is a small deposit of zinciferous rock upon which a few prospecting shafts have been sunk. The ore here is principally blende, and occurs in two vein-like sheets which cut diagonally across the bedding of a crystalline limestone country rock. They are close to the gneiss contact. The veins are five feet apart, with white limestone between them.

As already stated, lead does not occur in commercial quantities in New Jersey. Some galena has been found at the Andover iron mines, in gneiss. At the Sussex lead mine, near Howellsville, zinc blende and galena have been found in limestone adjacent to the contact with the gneiss, with which the beds of limestone are interstratified [*52*, *p. 681*]. The galena is disseminated in small strings and bunches. No vein or large pocket had been found at the time of examination, and no ore had been shipped. In the Oneida conglomerate of the Kittatinny and Shawangunk mountains, small quantities of galena have also been found.

MARYLAND.

The state of Maryland is credited with a few deposits of zinc ore, one of which gave promise of profitable development. Galena and other lead compounds apparently occur in small quantities. Dana [*57, p. 1071*] refers to galena, anglesite and cerussite, near Union bridge, in Carroll county, at the Mountain View lead mine. In 1890 this deposit was opened and small operations were conducted for some time [Williams]. Galena is also reported to occur in a vein in limestone at Unionville, Frederick county [*55, p 941; also 224*], at the Dolyhide copper mines; this ore is argentiferous and is in small quantities. It also occurs in dolomite, at Catoctin furnace, both of these localities being in the same county; also at Jones' falls, in gneiss, near Baltimore.

Zinc blende is reported to have been mined near New Windson, in Carroll county, where it is associated with some calamine and smithsonite. It also occurs with the galena in dolomite at Catoctin furnace [*224*]. A deposit of zinc ore and some galena is described by Dr. Persifor Frazer, in Carroll county [*89, p. 33*]. This deposit occurs on the land of Mr. Augustus Roop, less than two miles south of New Windsor. It is associated with ores of copper. The country rocks are Lower Silurian limestone and underlying hydro-mica schists. The copper ore is found principally along the contact between these two rocks, but it also permeates the limestone to a distance of from 5 to 15 feet from the contact. At one opening one line is similarly permeated with blende at about 10 feet from this contact. This is associated with ferruginous copper ore. Developments were not sufficient to show the amount of blende, but indications were favorable for an extensive mass. At another opening galena and blende were associated with the copper ore.

The limestone here lies in troughs and sharp synclines, with overturned dips at places. The full extent of the ore deposit had not been determined at the date of this paper; only prospecting had been undertaken.

According to the figures of the Tenth census, there were produced in Maryland during the year 1880, 672 tons of zinc ore. These are credited to Frederick county.

VIRGINIA.

The lead and zinc deposits of Virginia which have so far proved of commercial importance, are practically confined to the southwestern corner of the state and to Wythe county in that section. In the adjoining county of Pulaski, and beyond this in Montgomery, large deposits are reported to exist [*24, p. 340,*] [*240 p. 730,*] and galena and sphalerite are known to occur in Smyth, Washington, Bland, Russell, Scott, Giles, Floyd, Grayson, Stafford, Nelson and Franklin counties; but these occurrences do not seem to be of sufficient promise to justify much exploitation.

The principal deposits of Wythe county are at the Wythe lead and zinc mine, and at Bertha zinc mine in the southeastern corner. Other deposits are known to occur, but the developments so far have not shown them to be of great extent, and the distribution of the ore in them is found to be sporadic [*145*].

Wythe Mines.—The Wythe mines are the oldest and most extensive. They have also been known as the Union Lead mines and the Austin mines. The country rock here is an arenaceous magnesian limestone, known as the Knox dolomite, of Cambro–Silurian age. This rock is hard, much flexed and somewhat metamorphosed. The ore occurs in a hill about 250 feet high, which occupies an anticlinal axis. The deposit follows this axis. It is associated with brown iron ore. Shafts have been sunk and drifts have been run as low as the base of the hill, but little work has been done below water level.

Von Groddeck [*226, p. 103*] describes the original deposits as irregularly interbedded in the dolomite, in three layers 8 to 20 ft. thick, which are folded in the anticline along with the country rock. Prof. Stevenson [*214*] has designated them "enormous impregnated deposits." He describes a network of galena and blende veins in the limestone, together with masses of carbonate and silicate of zinc and galena of very open porous structure, which are probably of secondary formation. The great body of the ore mined is of this secondary class, and it is found in or under clay, whence it is removed by open-cut work or stripping. This clay is 25 to 30 feet thick, and of a red color and tough consistency. In it the zinc occurs mostly as silicate and carbonate. In general the galena is found at lower levels than

the silicate or carbonate of zinc. The clay carrying these ores surrounds domes or chimneys of limestone which have resisted decay. Concerning the origin of these ores, Von Groddeck expresses the opinion that they were simultaneously deposited with the limestone [*226, p. 104*].

Bertha Mines.—At the Bertha zinc mine and the adjoining Valley Cliff zinc mine the conditions of occurrence are apparently the same, and are, perhaps, better shown than in the Wythe mine. The ore is obtained by stripping, and also by an ingenious system of underground mining between the clay and the limestone chimneys. The clay has an average depth of 81 ft. and some 30 cubic yards have been removed for every ton of ore [*146, p. 632*]. In 1883 the opening was 425 ft. long and 60 ft. wide. In 1893 a strip 1500 ft. wide was worked [*25, p. 31*]. Throughout the area mined the limestone occurs in ridges and points, known as chimneys, over which are great thicknesses of clay. The zinc ore is found under this clay cover in large and small masses, filling depressions in the limestone and following along the walls of the latter, from which it is sometimes skinned off [*145, p. 54*]. The ores of this mass are chiefly carbonate and silicate of zinc carrying about 38% of metallic zinc. Some zinc blende also occurs disseminated through the limestones, and in irregular bodies, from which the oxidized ores are doubtless derived. There is a remarkable absence of lead and no tin, arsenic, antimony, copper, bismuth or cadmium are revealed by analysis [*67, p. 112*]. On account of its purity, the spelter from these ores commands a good market. Analysis has further shown that the clays associated with these ores contain at times as much as 12% of oxide of zinc. A very interesting and graphic description of these deposits has recently been published by Mr. W. H. Case [*38*].

The deposits of the Wythe mines have been worked for over 140 years. Mr. C. R. Boyd has recently written a very interesting sketch of their history [*26*], prepared for the occasion of a meeting of the stockholders. According to this, the deposit was discovered by Col. Chiswell, a British officer, about 1750, when mining of the galena was begun. Among other works, he drove a tunnel 25 feet through hard dolomite, in which galena was dispersed. Later, the deposit was worked for lead during the revolutionary war, and after this intermittingly by different individuals up to 1838. In 1836 Rogers describes these deposits [*192. p, 139*] as then worked for lead alone, the zinc ore

being rejected. The product was hauled to Baltimore in wagons. In 1838 the Wythe Lead Mines Company was organized, and continued work until 1848. up to which time they produced 3256 tons of metallic lead. In 1848 the Wythe Union Lead Mining Company was organized, which included the mines of the previous company. Under their control there were produced up to 1858, 3807 tons of lead, while various outside mines produced 1,300 tons more. In 1858 there was another reorganization, and the Union Lead Mine Company was organized to control all previous workings. This company continued operations until nearly the end of the war, and was the principal means of supply of lead for bullets for the Confederate government. During the succeeding years the following amounts were produced:

	Lead.
Feb., 1858, to May, 1861	1288 tons
May, 1861, to Feb., 1862	616 "
Feb., 1862, to Feb., 1863	421 "
Feb., 1863, to April, 1864	312 "
April, 1864, to Dec., 1864	293 "

The mining and milling plant, furnace, etc., were all destroyed by the Federals in 1864, but immediately after the war, in 1865, they were rebuilt.

Between the years 1866 and 1877, Mr. Boyd states [*27, p. 85*] that over 10,000 tons of zinc carbonate were shipped north for the manufacture of zinc oxide. Mr. O. J. Heinrichs estimates [*100, p. 345*] that the Wythe mines produced between the years 1838 and 1879, 12,167 tons of pig lead. In 1880, according to the Tenth Census Reports, there were 11,200 tons of lead ore and 10,448 tons of zinc ore produced in the state. In 1883 the Wythe mines were producing at a rate of about 12,000 tons of zinc ore (?) per annum. The Bertha mines have been opened comparatively recently, but up to 1886 some 12,775 tons of zinc ore had been smelted from these deposits.

NORTH CAROLINA.

In North Carolina the production of lead and zinc ores has been entirely incidental to gold and silver mining. The quantities of these base metals, though quite large in some localities, are in nowise adequate to have alone warranted the extensive and deep mining which has been prosecuted. The State, therefore, does not rank as a lead or zinc producer, though a good many tons of such ores have been mined and shipped.

Washington Mine.—This mine, in Davidson county, known later as the Silver Hill mine, is the most prominent of those yielding lead and zinc ores. The deposit was discovered about the year 1836, and was worked almost uninterruptedly until 1852. It was again reopened about 1855, and has since been the scene of large operations.

The ore occurs here in a series of veins parallel to the stratification of the country rock, which coesists of argillaceous schists. Emmons classed these as Taconic [*77, p. 185*]. The gangue is largely talcose, and the country rock adjacent to the lode is much decomposed. There are two principal veins which are nearly parallel to each other, and are separated by a distance of about 30 feet. They come together at a depth of 60 feet, but soon separate again and remain about the same distance apart. The ores consist of a mixture of lead, zinc, copper and iron sulphides, carrying gold and silver. In the surface workings carbonate and sulphate of lead are found, together with native silver. The thickness of the vein varies, generally, from a few inches to 12 feet; at one place it was as much as 60 feet, but the ore is much mixed with horses of schist [*129, p. 289*]. The total depth reached by the workings is about 600 feet, and the mine is thus one of the largest in the State. An analysis of a sample from a large pile of the ore showed the presence of 17 per cent of metallic lead and 45 per cent of zinc. This is probably not far from an average of the ore of the mine [*130, p. 195*].

Only a few figures of production are available at present. Whitney states that in 1844 [*234, p. 400*], 160,000 pounds of lead ore were produced, which contained $24,009 worth of silver and $7254 worth of gold. In 1851 he gives the production as 56,896 pounds of lead, containing $7942 worth of silver. In 1875 Kerr states that the pure ore was separated out by hand, and the remainder was buddled and roasted and shipped to New York for the manufacture of Bartlett's white lead. He gives the production at that date as about 400 to 500 tons per month.

Silver Valley Mine.—This is in the same county as the Washington mine. It lies about 5 miles northeast of Silver Hill. It was discovered about 1880. The country rocks are similar to siliceous and argillaceous schists. The gangue of the vein is quartz, containing little ore near the surface. The vein is from five to twelve feet in width, and is of laminated structure—the layers consisting of ore, slate and quartz. The ores at depths are similar to those of Silver Hill. Analyses show

them to contain from 15 to 55% of lead and from 11 to 32% of zinc. At the Wilborn mine, in the same county, similar ores have been found, but little development has been made.

In Cabarrus County, the McMackin mine was worked many years ago, though it has been abandoned now for about twenty-five years. The ores and their mode of occurrence are similar to the Silver hill deposits. At the Allen Furr and Rocky river mine, veins carrying galena have also been discovered.

In Union County galena and pyrite in quartz are found in veins, from three to four feet thick at the Smart mine. At the Lemmonds mine galena and blende are found in a similar vein which varies from three inches to six feet in thickness. Similar ores have been found at other points in this same county.

In Montgomery County are also a number of occurrences of zinc and lead ores. The most noteworthy of these is at the Steel mine. Here galena and blende with iron and copper pyrite carrying gold and silver occur in a bedded deposit. The productive portion of this bed is nine to twenty feet thick, and in it the ore aggregates from 15 inches to three feet in thickness.

Lead and zinc minerals are also found associated with gold and silver ores in Gaston, Cleveland, Cherokee, Wautauga, Wilkes, McDowell, and in smaller quantities in a number of other counties. From few of these have any ores been produced, however, and in some only surface specimens have been found. As defined by Hanna [*130, p. 188*], galena and associated ores in the state are practically confined to a belt which extends from the southern line of Union county in a northeasterly direction into the southeastern portion of Davidson county a distance of about 60 miles. The width of this belt is about five miles.

TENNESSEE.

Lead and zinc deposits in Tennesse are found mostly in the eastern part of the state. They occur generally in the Knox dolomite, of Cambrian or Silurian age. Though specimens and small veins and pockets have been found in almost all counties of this section of the state, workable deposits are few.

In Union and the adjoining county of Claiborne are occurrences which Prof. Safford at one time thought promising [*198, pp. 484 488*]. At the Caldwell mine in Union county, and at other points, galena was found in thin veins and also in grains and nodules, scattered through

the dolomite country rock: some pockets containing several hundred pounds of ore were also opened. The vein at the Caldwell mine was about 20 inches wide at the surface, and contained sheets of galena, blende and pyrite, aggregating five inches in thickness.

In Bradley, Monroe, Jefferson and Davidson counties a number of small lead mines have been worked in similar deposits.

The most important occurrences of zinc ores, according to Safford, are in Union, Claiborne and Jefferson counties. Reduction works were erected at Knoxville in 1883 [*220, p. 8*].

The Stiner mine, in Union county, was three or four miles southwest of the Caldwell lead mines. The ores occurred in the Knox dolomite, in a net-work of veins containing smithsonite and calamine, with a little galena and blende. The veins varied in thickness from a few inches to several feet.

At Mossy creek, in Jefferson county, zinc ores were mined and zinc-white works erected over 25 years ago. Referring to these deposits, Prof. Safford writes*: "I have visited Mossy creek since the report (1869) was printed. There are many irregular veins. The rock appears as if it had been broken up, and that then the mineral had been deposited in the crevices and upon spaces. In going down, the sulphide becomes relatively more and more abundant."

In Bradley county, near Blue Springs Station, new developments on a lead and zinc deposit have been made during recent years. Of these, Mr. A. L. Waters, of Blue Springs Station, writes that an opening 100 ft. deep and 200 ft. long has been excavated. Evidences of replacement of limestone by the ores seem good. The lead and zinc compounds are mostly sulphides. They seem to occur in two beds dipping about 70° N. E.

* Private communication, October, 1893.

LEAD AND ZINC DEPOSITS OF THE MISSISSIPPI VALLEY.

The principal lead and zinc-producing states of the Mississippi valley have been Wisconsin, Illinois, Missouri and Kansas. These have yielded very large quantities of ore, and continue to do so up to the present time.

Lead mining began in the Mississippi valley early in the 18th century. It was then confined to southeastern Missouri. The Wisconsin-Iowa deposits were not worked until nearly the year 1800. The utilization of the zinc ores did not begin until the year 1860. To date, the total production from the whole region is in the vicinity of 1,500,000 tons of lead, and about 2,000,000 tons of zinc ore.

WISCONSIN.

The areas, including the lead and zinc deposits of Wisconsin and immediately adjacent states, constitute collectively what has been called the Upper Mississippi lead region, in distinction to the Lower Mississippi lead region, which originally included only the deposits of eastern Missouri. There is great similarity between the deposits of the two regions, which, in itself, is reason for a somewhat extended description of these Wisconsin ores here. Moreover, these deposits have been subjects of more critical and exhaustive study than have the Missouri ores. We hence consider it important to enter with considerable detail into a statement and discussion of the results reached.

Area.—The state of Wisconsin contains about five-sixths of the Upper Mississippi lead region, the remaining one-sixth being distributed over contiguous portions of Illinois and Iowa. The area of the whole region is about 2600 square miles - its length in an east and west direction being about 65 miles, and its breadth in a north and south direction about 55 miles. It lies principally west of the Mississippi river and entirely south of the Wisconsin river. Within this region the deposits and ores are essentially of the same nature. Hence, under the present heading, we shall include a discussion of the whole, inasmuch as the Illinois and Iowa areas form part of this great whole and do not admit of a separate consideration. The brief references made to the deposits of these states elsewhere are supplementary, and not in repetition.

Topography.—The topography of the Upper Mississippi lead region is of the familiar type of much of the Mississippi valley. It is an eroded plateau in horizontal strata, through which the streams have cut sinuous courses. These streams flow through alluvial plains in valleys which themselves, in turn, are bordered by low bluffs or cliffs. The local ranges of elevation are slight. The extreme is not over 500 feet, and this exists only in the case of mesas or cones formed of outliers or remnants of overlying strata now largely eroded.

General Geology.—The rocks of the region include Cambrian and Lower Silurian strata, and in the extreme southern part, some Upper Silurian or Niagara beds cap the hills. The section of this strata as given by Irving [*121, pp. 489, 499*] is as follows:

	Formation.	*Thickness.*
	Niagara dolomitic limestone	300 ft.
	Cincinnati shales	60–100 "
Ore horizon.	Galena dolomitic limestone	250–275 "
Ore horizon.	Blue limestone	50–75 "
Ore horizon.	Buff dolomitic limestone	15–20 "
	St. Peters sandstone	90–100 "
	Lower Magnesian (dolomitic) limestone	250 "
	Potsdam sandstone series	800–1000 "

These strata spread over the region in great sheets, one upon the other. They have a general southward dip, such that in the northern part, along the Wisconsin river, the Potsdam sandstone and Lower magnesian limestone are exposed over broad areas. From here to the southern line of the state, a distance of nearly 50 miles, the fall of the galena limestone is about 500 feet. The surfaces of these formations are somewhat undulating, due to inequalities of the floor upon which they were deposited. Combining with these undulations and this general southward sinking of the strata, there is also a slight transverse flexing of post-Carboniferous age along an axis running in a N.W.–S.E. direction, through the heart of the region. This axis passes approximately from Warren, on the southern border of the state, through Belmont, and thence N. W. between Lancaster and Fenimore Center. What makes this line especially worthy of note is the fact that it divides the region into two parts; on each side of it mines are thick, while along the axis, over a belt some 4 miles wide, none of importance occur, and few of any kind have been opened. This flexure is of very gentle nature, however, along the northern border of the region—the fall toward the east or west amounting to only 200 or 250

feet in a distance of 25 miles. Certain minor flexing along E. to W. ores is also recognized; this, though not producing prominent structural features, is supposed to have had material influence upon the distribution and deposition of the ores.

As is indicated in the section given above, the principal ore horizons are the Galena dolomite and the Trenton, blue and buff limestone. Some ore is also found in the Cambrian, Lower magnesian dolomite, but the amount is of insignificant commercial value.

The Galena limestone is by far the most important ore horizon, and, of this, the middle portion has been the most productive. It is a hard granular dolomite, containing frequently small cavities filled with softer material or lined with minute calcite crystals. Unaltered it is of a gray or bluish color, but becomes a yellowish gray on weathering. On long exposure it also acquires a rough, honey-combed appearance, due to differential weathering. Clay and siliceous constituents are distributed through the rock, and there are also thin shaly layers interbedded, which, combined, are the sources of much of the residuary clay of this region. Chert occurs in this rock in thin layers, as a rule more abundant near the middle and lower portion, though this is by no means constant. Shaly constituents are decidedly more prevalent near the base. Portions of the rock appear brecciated. The beds are generally from one to four feet thick, but they are occasionally thin near the top and bottom. Fossils are comparatively rare, but there are indications of the former presence of abundance of life [*39, vol. iv, p. 407 et seq*].

The Trenton limestone is the next most important ore carrier. It is divided into an upper "Blue" and a lower "Buff" limestone, of which the first is the largest ore producer. At the top of the Blue, limestone, Strong [*39, vol. ii, p. 680*] describes a carbonaceous shale constituting a line of demarcation between it and the overlying Galena dolomite. This shale varies from a fraction of an inch to a foot or more in thickness, and, at one place, it was observed to be as much as seven feet thick.* The upper quarter of the blue limestone is thinly bedded and grades into the Galena limestone, though it is not dolomitic; it is very fossiliferous and contains beds of clay and shale from two to three feet thick. The lower three-fourths of this blue limestone is heavily bedded, hard, compact, very pure limestone, known as "Glass

* Mr. W. P. Blake is inclined to attribute to this shale and it contained carbonaceous matter, much influence in the formation of the ore bodies [*17*].

rock." Carbonaceous matter is, however, prevalent throughout in these shaly seams and partings, and vegetable remains are also present.

The Buff limestone is a dolomitic rock, sparsely fossiliferous. The upper portion is heavily bedded and is known as Quarry rock. The lower portion is thinly bedded and more fossiliferous. The rock is of even texture throughout.

The St. Peter's sandstone, immediately beneath the Trenton, is composed of well-rounded grains of sand with very little cementing material, though the rock is generally very friable and soft. As a whole it is a remarkably pure, saccharoidal sandstone. The thickness is very variable, ranging from 100 to 200 ft. This is largely due to the irregular and wavy nature of the contact with the Lower magnesian limestone beneath. This is a great water stratum and source of artesian water in the state. Only a little lead is found in crevices in the uppermost layers, which Chamberlin describes as thin, detached plates in narrow seams.

The Lower Magnesian limestone resembles the Galena limestone, in that it is a coarse, rough, often brecciated, thickly bedded dolomite. It is more siliceous, however, containing, in addition to chert nodules, much diffused silica and some quartz crystals in drusy cavities. The strata are much mingled with sand near the base of the formation, showing a transition into the underlying Potsdam sandstone. The upper surface of the formation is very rugged, indicating the action of erosion before the deposition of the succeeding St. Peter's sandstone. Organic remains are rare. As already stated, this is not an important ore horizon.

The Potsdam sandstone consists of a great body of strata 800 to 1000 ft. thick. It is sometimes calcareous, in fact in the upper portion there is a considerable thickness of arenaceous limestone and calcareous shale. The formation is water-bearing and a source of artesian supply. No lead or zinc ores are found in it, but, further north, iron and copper ores are included. Under this formation is the irregular surface or floor of Archean rocks, consisting presumably of the Huronian quartzites and quartz-porphyries.

The rocks of these various formations lie essentially conformably one upon the other. It is true that some evidence of intervening elevation and erosion exists, but this not to the extent of non-conformity. Thus a breccia which characterizes the upper layers of the Lower Magnesian indicates such an interval. This has produced inequalities

of surface which cause the great variation in thickness of the overlying St. Peter's. Chamberlin thinks that this has transmitted itself to the overlying strata also. Not, however, till toward the end or soon after the deposition of the Upper Silurian Niagara limestone was the region well raised above sea level. It then formed the Wisconsin peninsula in the Devonian and Carboniferous seas. Since that time the region has been continuously above water level, though subjected to surface oscillations. Thus, lowering of the land during Carboniferous times probably brought the seas to within less than 100 miles of the area, if they did not actually reach it. The whole of this northern lead region is in what is known as the driftless, non-glaciated area. Thus, since the Upper Silurian epoch, the region has been subjected almost continuously to sub-areal erosion. As a result, only a few patches of the Cincinnati shale and of the overlying Niagara limestones are left. Whitney [*235, p. 124*] estimates that a thickness of from 350 to 400 feet of these rocks has been removed.

Distribution of Ore Deposits.—As already stated, the principal ore horizon is of the Galena limestone, and of this especially the middle portion. The underlying Blue limestone, of the Trenton group, is also an important source of ores, particularly of zinc. In fact, it is a generally observed rule that the zinc ores occur at lower depths than do those of the lead, even when both are found in the same crevice.

With reference to structure, the deposits are noted to be most prevalent in depressions of synclines, and are comparatively rare at the crests of flexures. Chamberlin attaches much importance to this fact. Another consideration of interest mentioned by Whitney, is that deposits sink stratigraphically as erosion cuts deeper: that is, they extend into lower horizons, where the upper strata have been denuded, and thus seen to have closer relation to the surface contours than to the geological horizon.

Geographically, the lead ores are distributed over the whole region, but more thickly in the southern portion, about Galena and Dubuque. Zinc ores are more prevalent in the northeast about Mineral Point, Mifflin, Linden and Dodgeville, where low beds are best exposed. It is considered possible that deeper mining would reveal these zinc ores elsewhere. In general, Chamberlin concludes that the ore bodies may continue at greater depths to the south and southwest, and that, though they probably originally existed in these rocks beyond the Wisconsin river to the north, they gradually dwindled out to

the E., S. E. and N. W. The ores are generally most abundant along drainage channels, or on slopes of water-sheds.

Modes of Occurrence of the Ores.—The ore first mined here was found principally in residuary clays near the surface, and was known as float ore. Since then, however, the deposits have been generally found in vertical crevices or flat sheets in the country rock.

Vertical crevices characterize the galena limestone, and are pre-eminently lead-bearing. They rarely exceed 100 feet in depth, but are often several hundred feet long. They sometimes exist as fine seams, filled solidly with a thin sheet of galena. Elsewhere they expand to large caves as much as 50 or 100 feet long and 30 feet wide. At times, the walls of the crevice alternately separate and come together, so as to form several small caves, one under the other. In such caves, the ore generally occurs in masses or crystals; over the bottom, fragments of country rock and other detrital material are found in the clay. Sometimes the filling is almost entirely residuary, and in places the stratification marks are preserved with horizontal strings; nodules and sheets of the ore traverse the material. When open above, the remains of the mastodon, peccary, wolf and buffalo are sometimes buried in the clays of these clays. To these openings the name of "gash vein," so generally given to the deposits of this region, more particularly applies.

Flat sheets are most abundant in the Trenton limestone. Like the vertical crevices, they may be filled with solid sheets of galena or blende, though often associated with a gangue of calcite and sometimes of barite; or they may be more or less open or clay-filled spaces. A modification of these are the so called "flats and pitches." These ores extend downward generally on two sides from a central flat sheet in a series of steps, alternately transverse and parallel to a strata. The largest mines have been in deposits of this class.

Ores are also found in brecciated or honey-combed portions of the rock, and in caves and channels of irregular shapes and distribution. They also, in some places, impregnate the country rock to a slight extent. In general, they may be said to fill all the various crevices, cavities and interstitial spaces which characterize a decomposing limestone.

Two principal systems of crevices are recognized, of which the master system runs in an east and west direction and the minor system north and south. Subordinate to these are some quartering crev-

ices. Of the 4000 identified in the region, the number belonging to each of these systems is estimated respectively at 60, 20 and 15%. The remainder are irregular deposits not included in this classification. The maximum length of any single range of crevices is about three miles.

Faults with small throws were recognized by Percival as early as 1856. Attention has recently been called to them by Blake [*17*], who appears to consider them of influence in the deposition of the ores.

Ores and Associated Minerals.—The ores occurring in the crevices were originally almost exclusively the sulphides of lead and zinc, galena and blende; with these were associated pyrite, marcasite and chalcopyrite, calcite, some barite and dolomite, a little crystallized quartz, and, probably, some sulphide of manganese. Under the influence of the weather and the action of percolating oxidized waters, these original compounds have been changed in large part. The galena is oxidized sometimes to the sulphate, but generally beyond this, to the carbonate. The zinc occurs largely as the carbonate, smithsonite, known in this region as "dry bone;" this frequently replaces and assumes the crystalline forms of calcite. Some hydro-carbonate and a little silicate of zinc are occasionally found. The iron and copper compounds are similarly changed to various oxidized forms. The galena carries only a trace of silver. It generally crystallizes here in the cubical form. The blende is generally dark and opaque, is sometimes in crystals, but more often massive and stalactitic. Crystallized calcite is abundantly associated with the ore; but crystallized dolomite is comparatively rare. This is attributed to the greater solubility of the carbonate of magnesia. Barite is abundant only at a few localities. Crystallized quartz is very rare.

In the unaltered ore veins, the order of deposition of the original minerals is generally pyrite, blende, galena, and sometimes upon this pyrite again. These sometimes line the walls of cavities in concentric shells. One or more may be absent in any instance. Calcite is generally formed after these compounds, but it is irregular in this respect. Barite seems of still later formation and replaces calcite at times. Stalactites of blende or galena are sometimes found hanging from the roofs of cavities, and sometimes both are combined in one stalactite. One instance is cited where a crystal of galena terminated a blende stalactite. The decomposition products generally coat the parent com-

pounds, but they are also associated with other minerals somewhat indiscriminately.

The relative quantities of zinc and lead ores are somewhat difficult to determine. From analyses of the productions of large representative mines, Chamberlin reached the conclusion that the amounts of the two metals were about equal.

Source and Origin of Ores.—The origin of the Wisconsin zinc and lead ores and their mode of accumulation have been oft-discussed questions. Perhaps the most remarkable explanation offered by a professional man is that of Mr. Featherstonhaugh [*86, p. 50*], who passed through the country in 1834 as U. S. Geologist. He speaks of the ores as igneous injections similar to trap-dikes—a view no one familiar with the properties of these minerals could possibly advance.

Dr. D. D. Owen [*161*], as the result of his examinations during the year 1839, expressed the opinion that they were derived from below and owe their origin to the underlying granite platform. Just how they were so derived is, however, not explained. Dr. Percival, who was State Geologist in 1855, held apparently the same view.

Prof. Whitney, however, who, during the years preceding 1862, made an extended examination of the whole region, emphatically opposed the hypotheses advanced by Owen and Percival, and published his views in the report already referred to. The principal objections adduced to the theory of derivation from depths by thermal waters are the facts that faults are practically absent from the region; that the crevices are not deep and continuous like true fissures; that there is an entire absence of intrusive igneous rocks; that the underlying metamorphic rocks have been little disturbed since the deposition of the overlying sediments, and that the Lower Magnesian beds contain little ore and the Potsdam and St. Peter's sandstones none. Further, as Chamberlin added later, these sandstones are heavy water carriers, and it is almost impossible to conceive how metallic solutions would have been transmitted across the water-soaked and porous strata without having been diffused through them; it is further difficult to assign hydrostatic causes for the ascension of such solutions here from great depths.

Whitney's explanation starts with the assumption that the oceanic waters of the earlier Paleozoic times carried comparatively large quantities of metallic salts in solution. The localizing of the deposits he attributes to the abundance of organic matter in certain strata, caus-

ing the reduction and precipitation of metallic sulphides at the time the rocks were formed. These were subsequently segregated into crevices.

Chamberlin in his report [*39*, *vol. iv*] as State Geologist, as a result of further original and extended studies, adopts Whitney's explanation so far as the original source of the ores from oceanic waters is concerned, but departs from it in attributing the localizing to segregating effects of oceanic currents of the early Silurian seas. The ores were thus brought together and distributed through the sediments of the ore region. They were subsequently gathered into the crevices and cavities by the combined effects of the solvent action of waters percolating through the rocks, and the precipitating action of the surface waters carrying organic matter which flowed down through such openings as reached the surface. His objections to Whitney's theory are principally that organic remains occur abundantly in other portions of the same strata, and at other horizons than those in which the lead and zinc ores occur. Hence the cause offered by Whitney for local concentration is not exclusive. The hypothesis elaborated by Chamberlin involves the delineation of pre-Silurian land surfaces and the determination of the oceanic currents of that time. The conclusions he reaches do not share the objections urged against Whitney's, yet the process is of so highly a theoretical character that one hesitates about accepting it.

Chamberlin further recognizes that the ore is still in process of formation or concentration, both through the action of the original causes and through surface decomposition of previously formed ores.

Crevices and Caves.—The crevices and openings in which the ores are found, Whitney describes as originally simple joint-planes, resulting in part from earth movements and partly from shrinkage attending the consolidation and crystallization of the limestone. Chamberlin goes farther and explains how all the different forms have originated. The crevices he shows are parallel to the axes of flexure and have been formed by the bending of the rigid limestone. They hence tend to gape toward the convex side of a fold, and to this cause the widening of crevices downward is doubtless often due, as well as the peculiar "flats and pitches." All crevices are further subject to enlargement and alteration of contents by percolating waters. The difference in vertical distribution of zinc and lead, Chamberlin assigns to selective chemical affinity.

Distribution of Mines.—The geographical distribution of the ore deposits and the location and direction of the crevices are shown in great fullness and in detail in the maps accompanying Prof. Chamberlin's report. From this it is seen that the portion of the lead region lying south and west of the anticlinal axis referred to on page 136 is the most productive, and that the principal centers of mining are Platteville, Shullsburg, Hazel Green, Dubuque and Potosi. The portion north and east of this axis includes only three important districts, namely: Mineral Point, Linden and Dodgeville. In each of these districts many important mines have been worked during the past fifty years.

History and Statistics.—Previous to 1860 lead was mined exclusively. Zinc mining began about that time and increased constantly, and during recent years has been the principal object of work. About Mineral Point some of the oldest and most productive mines in the whole lead region have been operated. Among the most important here is the old Ross mine, which up to the year 1877 is estimated to have turned out not less than 4000 tons of lead ore, and twice as much zinc ore. The Dodgeville mines have also been important producers. They have been operated since the early forties.

Near Dubuque, the old Levins mine, as described by Whitney, was an interesting type of a cave opening. The shaft first descended to a depth of 90 feet, when the fissure widened out to 30 feet. At a depth of 130 feet, drifts were driven northeastward 875 and southeastward about 300 feet. The cave-like expansion proved to be about 100 feet long. The ore was found extending laterally and horizontally into crevices between the stratification planes, and it undoubtedly once extended in flat sheets across the opening. At the time of Whitney's examination, as much as 1000 tons of lead ore had been taken out, and as much more remained.

Near Linden are also a number of important mines. The diggings of the Linden Mining Co. were first opened in 1833. Up to 1863 there had been produced as much as 20,000 tons of lead ore, and much larger operations were continued afterward. These diggings were also known as the Heathcock mines. Up to 1877, Chamberlin estimates that, all told, as much as 21,000 tons of zinc ore had been produced.

These figures will suffice to convey some idea of the extent of the workings and the amount of the product of the larger mines in this region; we will now pass to a brief notice of the development of mining and the history of production.

The first discovery of lead in this region is thought to have been by Nicolas Perrot, about 1692; but there is some doubt as to the authenticity of this report. More reliable is the notice that Le Sueur found lead not far from the present southern boundary of Wisconsin in 1701, in his voyage up the Mississippi. In 1766, according to Prof. Irving, Capt. John Carver found lead in abundance at Blue Mound. The Indians then had "float mineral" in their possession, but they did not know how to make metallic lead from it.

The first mining, as already referred to, was at Dubuque, by Julian Dubuque, between 1788 and 1809. Brackenridge notes that in 1811 the Sac and Fox Indians about Prairie du Chien made 250 tons of lead with no other instrument than the hoe. Beyond this little or nothing was done until the year 1821, when attention was attracted to the region by American explorers. By the year 1827 mining had become quite general. Since then it has continued uninterruptedly to the present time, though it has now sunk to comparatively insignificant proportions. The years of maximum production were 1845 to 1847.

During the years of Dubuque's operations, lead was produced principally for local trading purposes. Figures of production for that time are not obtainable, but the amount could not have been large. Schoolcraft states that it was probably 10 to 20 tons per annum. For the years 1823 to 1853, Whitney gives a table of production for the whole region, which will be quoted later. For the years 1862 to 1876 statistics of production were collected in considerable detail by Mr. Moses Strong, of the last Wisconsin Geological Survey, and were published in the latter part of volume II of the reports. The following figures are extracted from that report. They represent furnace productions by districts:

TABLE OF LEAD ORE PRODUCTION BY DISTRICTS.

				Tons.
Beetown	district,	1868 to 1876,	inclusive	4,575
Platteville	"	1862 to 1876,	"	6,274
Potosi	"	1862 to 1876,	"	21,350
Hazel Green	"	1862 to 1876,	"	8,469
New Diggings	"	1862 to 1876,	"	14,593
Shullsburg	"	1862 to 1876,	"	12,710
Mineral Point	"	1862 to 1876,	"	14,604
Dodgeville	"	1862 to 1876,	"	9,636
Highland	"	1862 to 1876,	"	3,750

From itemized statements of the above districts the following table of lead ore production in Wisconsin is prepared:

TABLE OF ANNUAL PRODUCTIONS OF LEAD ORE.

	Tons.		*Tons.*
1862	8,519	1870	6,877
1863	7,553	1871	6,743
1864	6,507	1872	5,812
1865	7,169	1873	4,959
1866	7,014	1874	4,813
1867	6,911	1875	4,589
1868	6,934	1876 to Oct. 1	4,374
1869	6,714	Total from Jan. 1,'62 to Oct. 1,'76.	95,488

Outside of these Wisconsin smelters, there were others in operation in Iowa and Illinois which were producing at the following rates:

RATE OF PRODUCTION OF LEAD ORE IN 1876.

	Tons.		*Tons.*
Dubuque, Iowa, smelters	1,225	Elizabeth, Illinois, smelters	221
Galena, Illinois, smelters	1,700	Warren, Illinois, smelters	100

The total production of the whole region we are able to give with some fullness. Whitney's table for the years 1823 to 1853 is as follows [*234, p. 421*]:

TABLE OF ANNUAL LEAD PRODUCTIONS, 1823 to 1853.

	Tons of Lead.		*Tons of Lead.*
1823	168	1831	6,013
1824	87	1832	6,049
1825	332	1833	6,796
1826	479	1834	8,622
1827	2,590	1835	9,485
1828	5,552	1836	12,756
1829	6,671	1837	10,872
1830	5,970	1838	12,108

	Tons of Lead.		Tons of Lead.
1839	13,413	1847	27,042
1840	13,425	1848	23,869
1841	15,848	1849	22,012
1842	15,671	1850	19,900
1843	19,574	1851	16,593
1844	21,863	1852	14,302
1845	27,247	1853	14,903
1846	26,334		

For the same period, and extending beyond it to 1876, Mr. Strong gives the following table [*39, vol. ii, p. 750*]:

TABLE OF LEAD PRODUCTIONS, 1821 TO 1876.

	Tons of Lead.		Tons of Lead.
1821 to 1831	23,244	1872	7,000
1831 to 1841	55,718	1873	7,000
1841 to 1851	215,979	1874	5,400
1851 to 1861	161,334	1875	5,400
1861 to 1871	84,700	To October, 1876	4,500

For the years 1873 to 1879, we have the following table, taken from the Mineral Resources of the U. S. for the year 1882:

TABLE OF ANNUAL LEAD PRODUCTIONS, 1873 TO 1879.

	Tons of Lead.		Tons of Lead.
1873	7,336	1877	6,417
1875	5,600	1878	4,492
1876	7,196	1879	2,800

About the year 1879, Irving estimated the annual production of the region at from 5000 to 6000 tons of galena. The census figures for 1880 are as follows:

PRODUCTIONS OF LEAD ORE IN 1880.

	Tons of Lead Ore.		Tons of Lead Ore.
Wisconsin	1,728	Iowa	389
Illinois	772	Total	2,884

During 1886, according to the Mineral Resources of the U. S., the production was as follows:

PRODUCTIONS OF LEAD ORE IN 1886.

	Tons of Lead Ore.
About Shullsburg	612
" Mineral Point	500
" Galena	50

During the Census year of 1889, Iowa is not credited with any production of lead, and the figures for Illinois and Wisconsin are:

PRODUCTIONS OF LEAD ORE IN 1889.

			Tons of Lead Ore.
Illinois			173
Wisconsin.	Iowa Co	406	1678
	Lafayette Co	729	
	Grant "	483	
	Greene "	60	
Total			1851

Zinc ores, as already stated, were not utilized until the year 1860, and, hence, the figures of production are quite complete. The following table is extracted from Mr. Strong's report previously referred to. The ore, which was all consumed at LaSalle, Ill., came principally from Mineral Point; other districts shipping were Platteville, Councill Hill and Galena.

TABLE OF ANNUAL PRODUCTIONS OF ZINC ORE, 1860 TO 1876.

	Smithsonite tons.	Blende tons.		Smithsonite tons.	Blende tons.
1860	160		1870	2,215	3,707
1861	133		1871	8,309	4,652
1863	560		1872	13,848	8,126
1864	1,586		1873	10,269	7,545
1865	2,099		1874	7,562	9,751
1866	3,687		1875	5,939	10,269
1867	2,590	420	1876	6,085	8,590
1868	2,151	1,539	Totals	69,467	57,728
1869	2,274	3,127			

About the year 1879, Irving estimated the following production for the region:

Smithsonite	9,000 to 10,000 tons
Blende	7,500 "
Total	16,000 to 17,000 tons

The Census figures for 1880 are as follows:

Illinois	3,000 tons zinc ore
Wisconsin	4,617 " " "
Total	7,617 tons zinc ore

In 1886, the Mineral Resources gives the following figures of shipments:

From Shullsburg	715 tons of zinc ore
From Benton	2,275 " " " "

For the Census year of 1889 the production is given as fellows:

Iowa			450 tons zinc ore
Wisconsin	Iowa Co.	16,996	24,832 " " "
	Lafayette Co.	7,132	
	Grant Co.	704	
Total			25,282 tons zinc ore

For the year 1893 Mr. Blake gives 3500 tons as the production of zinc ore [*195, vol. ii, p. 625*].

Imperfect though the above figures are, they are yet sufficient to show that a comparatively small part of the lead product of the State has been mined during the past forty years, and that the rate of production is steadily declining. The zinc ore production, however, which declined during the latter seventies and early eighties, showed a strong revival in 1889. The figure for 1893 shows an equally strong decline.

ILLINOIS.

Both lead and zinc ores are found in Illinois, principally in the extreme northwestern corner of the state, in Jo Daviess and Stephenson counties, which belong to the Wisconsin area. Small quantities of both metals have also been found in the southern extremity of the state, in Massac and Hardin counties.

The ores of the northwestern corner consist of galena, accompanied by very little carbonate or sulphate, and of zinc blende and the carbonate, smithsonite. The ores occur here principally in the Galena limestone, but are also found in the underlying Trenton rock, known

as the Blue limestone. The former is a dolomite, the latter consist partly of purely calcareous beds.

The principal area of mining in this district has been in the vicinity of Galena. Whitney [*233, p. 155*], writing somewhere between 1861 and 1865, states that nearly all the ore-producing diggings are included in a radius of four miles from a point a little northeast of Galena, and probably nine-tenths of the ore raised comes from this territory. This country was settled about the year 1820, and lead mining was in actual progress by 1827. Whitney states that the period of greatest lead production was from 1840 to 1850, the maximum being about 1845. At the time of writing his report, five lead furnaces were being run in Illinois. The zinc ore was made no use of during early years of lead mining, but, later, attempts were made to reduce it, and in the early sixties zinc smelters were erected at LaSalle and Mineral Point, in Wisconsin. These will be referred to later.

The production of this district in Illinois it is almost impossible to obtain, inasmuch as the shipments are included with those of Wisconsin and adjoining Iowa areas. Figures for the whole district have already been given in connection with the Wisconsin deposits. At the present very little mining of either lead or zinc is being done in Illinois.

The deposits of Hardin and Massac counties, above referred to, are found in vertical crevices or veins in the St. Louis limestone. Similar bodies occur across the river in Kentucky, and will be described at some length in the next section. The principal vein is near Rosiclare in Hardin county. It was discovered about 1839. This is termed by Mr. J. G. Norwood [*160, p. 365*] a "gash" vein. The ore consists of galena and zinc blende, with a gangue principally of fluorspar, banded with the typical ribboned structure. The galena contains nearly as much as nine ounces of silver to the ton. Several veins are recognized here with courses varying from N. 3° E. to N. 35° E. These, according to Emmons, occupy fault fissures [*82, p. 31*]. In places the vein is enlarged to cavern-like dimensions. Thus, at the Good Hope engine shaft, a cavern was encountered 10 to 12 feet wide, 30 feet long and as much as 20 feet deep, with sides and top encrusted with fluorspar, while the lower half was filled with decomposed spar, ochreous clay and loose masses of galena. Pockets in the limestone coated with galena crystals were also found. The Lead Hill mines in this county are also in a deposit of note. These veins of southern Illinois,

though of an interesting character, have been comparatively small producers of lead, but have been quite extensively worked during recent years for fluorspar. An excellent and recent detailed description of these deposits is given by Mr. S. F. Emmons, in the paper above referred to.

During the Census year 1880, the total production of lead ore in the state is given as only 772 tons. That of zinc ore is placed at 3000. In 1882 the Galena district is referred to as still an important zinc-producing camp [*240, p. 366*], but, according to the Mineral Resources for 1883 and 1884 (p. 426), lead mining had almost ceased in the state at that time. In the Census returns for 1889 no zinc ore is credited to Illinois, and the production of lead ore is only 173 tons.

KENTUCKY.

The State of Kentucky, though not classed as a producer of lead or zinc, contains yet some extremely interesting deposits of these ores which have been operated to a small extent. These deposits occur in the western extremity of the state, principally in Livingston, Crittenden and Caldwell counties, in the low-lying country traversed by the Ohio and Cumberland rivers and their tributaries. They are associated with the St. Louis limestone of Lower Carboniferous age, and belong to the same group as the Rosiclare deposits, across the river in Hardin county, Ills. In other parts of the state galena is reported to occur sparingly [*65, p. 735*] in the same rocks in Anderson, Fayette, Livingston, Owen and Cumberland counties, associated in places with barite and fluorspar; also in Carter county in the eastern part of the state, and in Boyle, Mercer, Garrard, Jefferson, Woodford, Anderson, Franklin and Henry counties in the center of the state.

The lead region of Livingston, Crittenden and Caldwell counties was examined and reported upon by C. J. Norwood in 1875 [*159, p. 457 et seq.*] According to this report, the existence of lead was known to the early settlers, and the ore was mined to a small extent by them. During the years between 1865 and 1875, however, most of the exploration was done, and the greater part of this during the last two years of that period. No extensive mining was, however, undertaken. The shafts were generally from 10 to 50 feet in depth, and only in one instance, at the Royal mine, did a shaft extend as deep as 175 feet.

In Livingston County the ore is described by Norwood as occurring in a fissure between limestone and sandstone walls. The sandstone,

which is quartzose and cherty in character, appears to be in the shape of a wedge in a crevice in the limestone. This wedge is sometimes 50 feet across, but is generally under 25 feet. It stands nearly vertical, or dips at angles of from 60° to 80°. The rocks on either side of the sandstone, he states, are seldom of the same age. The explanation offered for this peculiar phenomenon is: that the enclosed sandstone bed was originally part of a horizontal layer overlying the contiguous limestone; that the country was traversed by great earth movements, producing faults and open fissures, and that the slab of sandstone was precipitated into these fissures by a subsequent movement. This, to say the least, is a somewhat remarkable explanation. Mr. Norwood himself states that such sandstone is not recognized in place in horizontal strata immediately about the deposits, and that dike-like masses of sandstone are frequently found protruding from the ground [*159*, *p. 460*]. Emmons [*82*] defines these "dikes" as vertically sheeted masses (presumably of the country rock), produced by fault movement, and subsequently silicified. If the rock has anything of the texture of a sandstone, it is difficult to see how such a cause could produce such an effect. Without having personally examined the ground, it may perhaps be hazardous to offer a substitute for these explanations. From known occurrences in Missouri, however, we are inclined to think that these vertical and dike-like sheets of sandstone resulted from the silting of sand into crevices previously formed in the limestone. These crevices may have originated through faulting, or may be along contraction joints. Their enlargement is probably in all cases due to the solvent action of percolating waters. Sand of a later geological formation would naturally settle readily into such crevices, and would become consolidated there. The flow of percolating waters, after the emergence of the rock above water level, would tend to produce fresh openings along the contact between the sandstone and limestone country rock. The sandstone, being a good water carrier, would hasten this action on its lower side. In such secondary crevices the ore and associated gangue are now found.

The ore in these crevices consists of granular and crystallized galena in a gangue of fluorspar, calcite and limestone associated, and sometimes mixed with red or greenish clays. The evidence of extensive faulting leads to the conclusion that the fissures extend to great depths, but the ore-bearing portion has not been found to extend below the base of the Lower Carboniferous limestone.

Concerning the derivation of the ore, Norwood concludes that metallic sulphides existed originally as bedded veins, or as segregations and impregnations in and near the top of the St. Louis limestone. At the time of faulting and fissuring, he suggests that the metal may have been mechanically thrown into the crevices, as was the sandstone, in the manner above explained. Or, what is more probable, he suggests that the ore was eliminated from the overlying and decomposing limestone and redeposited from the solutions in the fissures below. The order of deposition he states to be first galena, then fluorspar, and later calcite. He is emphatic in stating that the theory of the derivation of the ore from *above* rather than from below is necessary to satisfy all requirements. The fluorspar has a bituminous odor, and bitumen is often found in crevices here.

Three faults or lodes are recognized traversing this county. The Fairview fault is near the western edge, and has a course of N. 32° E. It is considered to be the same as that of the Rosiclare vein in Hardin county, Illinois. The other two are the Latrobe and the Excelsior, through the southern portion of the county, which have a course of from N. 30° E. to N. 57° E.

The Royal Mines, near the mouth of the Cumberland river, are located on the Latrobe lode. As these mines are the most important of this district, we will repeat here, briefly, part of the description given by Mr. Norwood [*159, p. 470*]:

"These mines, formerly known as the 'River Valley mines,' are situated on the Cumberland river, near a well-known knob designated as 'Bissell's mount.' Of the three shafts sunk, only one is open for work at present; it is 175 feet deep, being the deepest of any in southwest Kentucky.

The shafts are situated on the Latrobe lode, the character of which is well defined. On the west side of the fissure, which varies in width from 8 to 15 feet, the St. Louis limestone is exposed, showing a thickness of 105 feet. On the east side the quartzose sandstone is also well exposed, exhibiting a width of about 12 feet and standing nearly vertically, inclined at an angle of perhaps 75 degrees.

Immediately east of the sandstone, thin limestone beds of the Chester Group crop out, resting on edge. Then the limestone terminates and blue calcareous shale comes to view. One hundred feet beyond where the shale sets in the rocks are once more nearly horizontal, a jointed sandstone (equivalent to the sandstone seen at Smithland ?), some 10 feet or more in thickness, coming to view, standing out in a vertical escarpment.

All the rocks included between the St. Louis limestone and this Chester (?) sandstone are tilted at high angles, dipping about southeast. The St. Louis limestone, however, is almost horizontal, and the Chester sandstone dips very little; course southeast. The sandstone is about on a level with the top of the St. Louis

limestone. There is evidently a very considerable drop in the rocks where the sandstone is exposed, as the Bissell mount shows at least 75 feet of additional limestone coming above that at the shaft.

Very little knowledge concerning the new shaft was gained, but Mr. Walton, the superintendent, states that the quartzose sandstone disappears at 150 feet from the top of the shaft, and limestone takes its place.

The lead is sprinkled through fluorspar in granules, small cubes and bunches. The masses of galena vary from less than the size of a pea to crystals half an inch in diameter.

According to the statement of Col. Callahan (formerly one of the proprietors of the mine), the fluorspar (carrying galena) was met with at 16 feet below the surface.

The spar was about two feet wide, with blue clay on each side of it, making up eight feet, the width of the fissure. The clay had many "boulders" of quartzose (?) rock, with drusy cavities set with fluorspar crystals. Thin seams of fluorite and of calcite also occurred in them, as well as occasional particles of lead.

This was the structure of the vein for the first ten feet. At that depth the spar disappeared and the entire fissure was filled with clay and boulders. The lead disappeared with the spar, and was found on the hanging-wall.

This continued for about 50 feet. Then there was 40 feet of "porous rock," with a little clay on each side. No lead was found in it, but was still seen coating the hanging wall. Upon passing through the "porous rock" a siliceous bed, containing mostly fluorspar, was encountered, and constituted the vein for 25 feet. No lead was found in it. At the termination of the 25 feet a dark, green shale, 3 to 5 feet thick, full of iron pyrites, was entered. Upon passing through the shale, fluorspar, bearing galena, was once more obtained.

The foregoing is, of course, not presented as being strictly accurate, but is sufficient to show the great irregularity in the structure of the vein."

In Crittenden county, the lead deposits are in many respects similar to those of Livingston county. They occur in the same rocks and are found in crevices. In some of these a sandstone wall-rock occurs also. At most of the mines, however, the wall-rock is limestone on both sides of the crevice. Usually, also, the mass of the rock is traversed by fissures running in various directions, and is honey-combed by caverns and smaller openings. The galena is associated with fluorspar, calcite, blende and siliceous matter.

The Columbia mines, about five miles west of the town of Marion, are the oldest in the southern part of the state. Here the Glass shaft was in operation at the time of Mr. Norwood's visit, and the deposit is described as follows:

"The galena lies in large masses and cubes, distributed through fluorspar, calcspar and siliceous material, the latter predominating. The depth of the shaft at the time when the mines were visited was said to be 38 feet, the width of the vein varying from one to five feet.

In sinking the shaft, the material passed through in the first 19 feet consisted of red clay, with fragments of limestone and masses of galena enclosed in spar and siliceous matter, distributed through it. According to Mr Tompkins, two wall-rocks were found at this depth, limestone on the west and sandstone on the east, continuing thus to the bottom of the shaft, with no clay between, except in cavities in the vein material *

In the next 10 feet the crevice varied from one to five feet in width, entirely filled with spar and siliceous matter bearing galena.

About 20 per cent of the material taken out of this space was lead. In the lower eight feet the vein averaged four and a half feet in width, with an increase in the percentage of lead. Judging from the appearance of the material piled near the mouth of the shaft, the percentage of lead may be estimated at one-fourth or a little more. This may be an over-estimate, however, as there is much zinc blende accompanying the galena.

Work at this shaft was suspended when the locality was visited. Mr. Glass states that there was no perceptible decrease in the quantity of lead toward the bottom.

---

*At the time of my visit the shaft had 15 ft of water in it, and no opportunity was afforded me to see the sandstone. I cannot, therefore, account for its presence. It is not visible on the surface, and this is the only shaft in which sandstone is reported. The walls of the one just a few yards north as well as of all the others are *limestone*."

In Caldwell County, the galena generally occurs filling small cavities or in bunches on the walls of the cavern. At Mr. Marble's shaft are several veins having a nearly east to west course. The width of the fissures is very irregular. The deposits of this county resemble those of the Columbia mines of Crittenden county more than they do the Livingston county deposits. Very little development has been done here, however, and the opportunities for the study of the deposits were few and poor.

IOWA.

The lead and zinc district of Iowa is, like that of Northern Illinois, part of the larger Wisconsin area, which has been described at length. Only a brief reference will hence be made here to the Iowa deposits. The productive mines of the state are confined to the vicinity of Dubuque, in Dubuque county. Small deposits have also been operated in the southeastern corner of Clayton county, south of the mouth of Turkey river. Further, galena and some blende have been found farther north, in Allamakee county, near the Upper Iowa river. The deposits of Dubuque, as well as those of Clayton county, are contained in the Galena limestone and in the underlying Blue or Trenton limestone. The ores consist principally of galena; some blende, as well

as smithsonite and calamine, are found in the lower workings. These ores occur in vertical crevices and "openings" and in flat sheets.

Mining was begun about Dubuque before the end of the last century, according to Whitney [*236, p. 424*], by Julien Dubuque, who obtained a grant of land on the west bank of the river. The country did not pass out of the possession of the Indians, however, until about 1830. In the years immediately following this, lead mining was actively prosecuted, and has been intermittingly continued up to the present time.

Statistics of production for this Iowa area, apart from the adjacent Wisconsin and Illinois areas, are few and difficult to obtain. White wrote [*230, vol. ii, p. 339*] in 1870 that lead mining was then in a moderately prosperous condition in the state, though it had been more so in the past. He further stated that no practical use had been made of the zinc ore so far. In the Report of the Tenth Census, Iowa is credited with the production of 3[illegible]4 tons of lead ore, but no zinc ore. In Bulletin 80 of the Eleventh Census, Iowa does not appear as a producer of lead, but 450 tons of zinc ore are stated to have been produced there during 1889.

MICHIGAN.

Michigan, though a great mining state, is apparently destitute of lead and zinc ores. Only a few occurrences of the compounds of these metals do we find recorded [*57, p. 1086*], and these are all in the Upper Peninsula. Thus, in Marquette county galena, and sphalerite are found at Presque Isle, at Marquette and in the Holyoke mining district. In Gogebic county these minerals occur at Copp's iron mines.

MINNESOTA.

Minnesota is, like Michigan, a state in which lead and zinc compounds occur only in very small quantities. Notwithstanding the fact that the Galena limestone and underlying Trenton beds, which are such prolific sources of these metals in the adjacent states of Wisconsin and Iowa, extend into Minnesota, they are here almost barren of the ores. Thus, in Fillmore county, in the southeastern corner of the state adjoining Iowa, the Galena limestone is abundantly exposed, but no ore is found in the rock, though occasional lumps of galena are scattered over the surface [*243, vol. i, p. 319*] [*244, p. 69*]. Winchell notes this fact (as well as the absence of the ore in the Trenton rocks) in

evidence that the age of the rock has nothing to do with the presence of the ore; that it is to be attributed to extraneous causes.

In Olmsted county, fragments of galena are sometimes found on the surface; it is also reported to occur at Duluth, in St. Louis county. Zinc blende is found at Stillwater, in Washington county [*84*, *p. 698*].

In Winona county, Winchell [*243*, *vol. i*, *p. 259*] refers to the occurrence of galena in a crevice in the St. Croix sandstone at the base of the Cambrian. A few shallow shafts were sunk here many years ago, and more recently another one. The galena occurs attached to the walls of the crevice, which follows a fault plane. It is in part changed to carbonate. Some pyrite is also found. Galena is also disseminated to a certain extent through the country rock adjacent to the crevice. Near the top of the bluff, close to the shaft, galena is also found sparingly, in fine joint crevices, accompanied by calcite.

KANSAS.

The lead and zinc-producing area of Kansas is an exceedingly small one. It is situated in the southeastern corner of the state, in Cherokee county, adjacent to the Missouri line. Most of the productive mines are included within a radius of a few square miles of the town of Galena, and they all lie east of Spring river.

A small quantity of galena has been found in Miami and Linn counties, where a number of attempts have been made to mine the ore, but none have proved remunerative. The galena occurs in small crystals in a large body of Coal Measure shales; also in thin laminæ between beds of sandstone and shale. According to Swallow, these shales are somewhat disturbed and fractured [*218*, *p. 58*]. The deposits are of no commercial importance.

The ores of Cherokee county occur in Lower Carboniferous limestone. The bodies fill great cavities in the country rock. They consist largely of fragments of chert, in places cemented by a dark quartzose matrix. Elsewhere, the spaces between the chert fragments are filled with clay, sand and other residuary products. In this material, as well as in the dark quartzite, the metallic minerals are found. They consist principally of zinc blende and galena. These deposits belong geologically and commercially to the Joplin district of southwestern Missouri, and are in all essentials similar to the latter. They hence receive full attention in the description and discussion of Missouri ores. Further reference to them, therefore, will be omitted here.

Lead ores were discovered in Cherokee county about 1872, and mining was begun soon after. The production of this Kansas field is generally included in statements including the whole Kansas and Missouri lead and zinc district. In the table of productions by states given in chapter VI, a separation is made. Data of lead ore productions are very scarce.

Previous to 1891 some lead ore was smelted in Kansas, but since that time it has all been sent out of the state, mostly to St. Louis and Illinois. Zinc ore, however, is smelted in large quantities in Kansas, much of the Missouri as well as the Galena product supplying the furnaces. There were during recent years as many as 76 furnaces in the state [*92, p. 127*]. These are located at Weir City, Pittsburg, Girard, Scammon and Galena. Further reference will be made to these furnaces and their processes in the chapter on the zinc industry.

ARKANSAS.

The most noteworthy occurrences of zinc and lead ores in Arkansas are in the northern portion, especially in Marion county, but also in Independence, Sharp and Lawrence, in Searcy, Newton, Boone, Carroll, Madison and Washington counties. Deposits of these ores also occur in the central and southwestern portions of the state, in Pulaski, Montgomery, Polk, Pike and Sevier counties; in these, however, the zinc and lead contents are of subordinate importance, silver and antimony being the substances principally mined for.

Northern Arkansas.—The deposits of the northern portion of the state, as exhibited in Carroll, Boone, Marion, Sharp and Lawrence counties, occur in magnesian limestones of probable Silurian age; while in Washington, Madison and Searcy counties lead ores are found in limestone of Lower Carboniferous age. At many of the points, however, where lead ores have been noted, merely loose fragments have been found, and no well-defined deposit is developed.

The ores of these counties were described by Owen [*258, pp. 46-241*] as irregularly distributed in crevices and along joint-planes, which are often vertical and have generally a northeastern to southwestern trend. These crevices frequently enlarge into pockets or cavernous spaces filled with ore, clay and other gangue. At some points the ore has impregnated certain strata, and thus occurs at a definite horizon. H. M. Chance describes such in the Rush creek district in Marion county

[*41, p. 505*]. One such horizon recognized there is above drainage level and hence is readily attacked in mining.

The zinc ores consist principally of the carbonate (smithsonite) and the sulphide (sphalerite); some silicate (calamine) is also found. The lead ore is principally the sulphide (galenite), but the carbonate (cerussite) is also found. Only desultory mining has been done in the deposits of these northern counties, and comparatively little ore has been excavated, and still less has been shipped—the means for transportation being very poor. From Marion county, some shipments have been made in flat-boats, down White river to Batesville, amounting to 350 tons in 1892 [*195, vol. i, p. 466*]. During the Census year 1889, the production of the state was 130 tons.

Personal examinations of a few of the openings in these ores were made by the writer in the spring of 1893. The following paragraphs are prepared from notes taken at that time:

Dodd City.—The Marble mine was situated about a mile north of Dodd City, in Marion county. A shaft was sunk 70 ft. deep, passing through the following section:

1.	Ore body, consisting largely of broken chert, with blende, calamine and smithsonite	54 feet
2.	Open ground, consisting of sand and angular fragments of quartzite—no ore	about 12 "
3.	Limestone breccia containing blende	" 4 "

The immediately adjacent country rock is a hard sandstone or quartzite. The ore seems to occur in a pocket filled with fragments of this sandstone, cemented by a drab secondary chert, in which latter the blende is found disseminated. The ground is very hard. A little lead was found near the surface. Some calcite occurs, but no pyrite.

The Bear Hill shaft is about two miles southeast of Dodd City. The shaft was probably 90 or 100 ft. deep. It penetrated a drab limestone in which blende was found in crystals in crevices between fragments. A tunnel driven into the hillside, about 10 ft. below the top of the shaft, entered a breccia of sandstone and limestone fragments cemented by a sandy matrix. Clay openings found in this contained smithsonite. The top of the shaft is about 40 ft. below the base of the marble beds belonging to the Lower Carboniferous Boone chert of the Arkansas Survey. Under this, are beds of drab magnesian limestone and white sandstone, some of the latter being hard and indurated. The beds of limestone and sandstone seem to merge into each other.

The Beaty or New South mines, are in section 1, township 19 N, 17 W. The ore occurs about 100 ft. below the marble beds. It is exposed in the bed of a creek, in a stratum of brecciated limestone, about 3 ft. thick. This rock consists of angular fragments of drab limestone, held by a calcareous matrix, in which the blende is found. The stratum is apparently not continuous, but passes into un-

broken rock. Above this stratum are openings in the magnesian limestone which also contain ore. Mining has been done by an open cut along the bed of the creek.

At the Placer or North Star mine, openings were made along the hill side about 80 ft. beneath the marble beds. The face exposed in these diggings was of sandstone, in which the ore occurred along the joints and crevices. In depressions, smithsonite was found imbedded in clay. Near by, the carbonate was found following the stratification planes, associated with secondary chert and drab chert and some decomposed limestone, all much intermixed. These were interbedded with the country rock.

The Rush Creek Mines.—Along Rush creek have been the principal developments of zinc ore in northern Arkansas. These are the deposits which have attracted most attention.

The Morning Star mines are situated about 200 ft. above the creek on the hill slope. The ore occurs in openings or pockets in a siliceous magnasian limestone, which is much decomposed in places and is traversed by clay openings. The principal compound is smithsonite, which occurs in mamilated forms, lining the sides of the openings and penetrating crevices of the rock. Some blende, of dark color, is also found. Much crystalized quartz is seen here which is deposited on the blende. A secondary chert of drab color is abundant and contains angular fragments of limestone. Some crystalized dolomite was also found. Very large blocks of ore have been obtained here. One seen by the writer was over 10 ft. in diameter.

The White Eagle shaft is near the mouth of Rush creek, about 150 feet below the Morning Star openings. A drift into the hillside at the top of this shaft showed smithsonite. The shaft was 80 feet deep and reached about 40 feet below the creek. The ore was struck at 66 feet, and is said to be 3 feet thick and to consist of blende.

The Last Chance mine is on Clabber creek, less than a mile east of Rush creek. The ore occurs here in horizontal streaks between beds of siliceous, magnesian limestone. A drift was driven 60 feet along a horizontal clay opening. The walls were partly dark secondary chert, with small crystals of blende scattered through it. Carbonate of zinc lines the side of the clay openings. The Last Chance tunnel, a little east and about 50 feet above the drift, was driven in "open ground," consisting of layers of red clay between undecomposed beds of limestone. These layers were 3 to 6 inches thick, and the aggregate thickness was about 6 feet.

The Leader tunnel near by, but about 100 feet lower, was driven 150 feet into solid magnesian limestone. No deposits were encountered other than small pockets containing blende and smithsonite, and these were only at wide intervals.

Concerning the origin of these ores, Dr. J. C. Branner, the State Geologist, in a private communication to the writer, says: "So far as the north Arkansas zinc deposits are concerned, I am as confident as one can be of such things: that they are derived from the rocks in which they occur, and that they are not veins filled from below, except where, in a very limited way, the waters have risen somewhat on account of the head given them by the dip of the rocks." He further

adds, with relation to the statement that these deposits occur along fault fissures, that only some of them do so, and that in such cases the faults have simply afforded the crevices in which the ores have accumulated. Where the cavities have been produced in other ways, they also have been filled by the ore.

Central and Southwestern Arkansas.—Of the deposits of central and southwestern Arkansas, those in Pulaski, Polk, Pike and Sevier counties are in Lower Carboniferous rocks, while those of Montgomery county are in Lower Silurian rocks [*258, pp. 17–145*] [*49*]. The conditions of occurrence of the ore are, however, not dissimilar. They exist in veins traversing, generally, shales or indurated slate tilted at a high inclination. The ores consist, principally, of galenite and sphalerite; the veins of Sevier county also contain large amounts of stibnite. The gangue is principally quartz and calcite, both frequently crystallized in cavities. Comstock remarks that no carbonates of lead or zinc are found.

The Kellogg mine in Pulaski county is probably the most noted. It is situated about 10 miles northeast of Little Rock.

The country rock is a black shale dipping southeastward at an angle of about 40°. A slope is sunk in this at an angle of about 58° south, and a streak of sphalerite was encountered at a depth of 38 feet, conformable to the bedding plane of the shales and varying in thickness from three to six inches; a quartz gangue about one foot thick accompanied this ore; about 60 feet deeper is a well-defined streak of galenite, parallel to the upper vein; some chalcopyrite accompanies this. The results of a large number of assays show that the galenite carries from 30 to 60 ounces of silver to the ton, while the sphalerite carries less than 20 ounces [*49, p. 5*].

The McRae mine is in the southwestern corner of Pulaski county. Little work has been done here, however. The ore consists principally of galenite mixed with pyrite, and yielded to the assay 3½ ounces of silver to the ton.

In Montgomery county, a large amount of digging has been done, principally about Silver City. The important mines of this locality are the Waterloo, Minnesota, Montezuma, Walnut and Eureka Lode. These operate veins traversing the country rocks, which consist of black shale or slate, frequently parallel to the stratification, and with a dip 60° or more. The gangue is quartz and calcite and the ore is

principally galenite and sphalerite; associated with these are pyrite, chalco-pyrite, azurite and argentite, according to Conrad [*51, p. 172*]. All of these ores are argentiferous, and some of them contain traces of gold. The silver contents, according to assays of the Arkansas Geological Survey, range from 17 ounces to 36 ounces per ton. The Rubicon mine, near Virginia City, in the same county, is operated in a deposit of a similar character. Though a large amount of mining has been done in this county, it can hardly be considered to have passed the stage of exploration; considerable amounts of good grade ore have been taken out, but the steep inclination of most of the veins, and the increase of water as depths were reached, has caused the abandonment of work in many cases. Hence, no shipments of silver or lead are quoted from this region.

In Sevier county we have a number of mines about Antimony City, in the northeastern corner. Among these, the Antimony and Antimony Bluff mines are prominent. West of these, is the Silver Hill district, where the Davis and other mines have been operated. The ores here, as in Montgomery county, occur in veins traversing black shale at a steep inclination. The gangue is quartz. The ore consists of galenite, sometimes intimately mixed with stibnite, elsewhere separated from it; the associated minerals are sulphides of iron, zinc, copper, bismuth and cadmium. At the Davis mine, the ore carries as much as 30 ounces of silver to the ton. These mines are operated continuously, and are the source of a large portion of the antimony used in the country. The lead product from here, as well as from other mines of central and southwestern Arkansas, is a secondary consideration, and the zinc product still more so.

THE LEAD AND ZINC DEPOSITS OF THE ROCKY MOUNTAINS AND GREAT BASIN.

This is a region which has been remarkable for the size and richness of its individual bodies of lead ores. These have been, moreover, highly argentiferous, which has stimulated their development in localities where the lead in itself would not have repaid working. The mining of these ores began not over twenty-five years ago, and, during the last two decades, over three-fourths of the total lead production of the country has been supplied from this region.

COLORADO.

The state of Colorado is the banner state of the nation in the production of lead. Zinc is not classed as one of her products, though many of her ores contain that metal, from which ores zinc compounds are extracted, and various zinc products manufactured. Thus, at Canon City is the American Zinc-Lead Co., which, during the year 1892, is reported to have manufactured, among other products, 2,500,000 pounds of zinc-lead pigment, equivalent to 1,125,000 lbs. of zinc [*195, vol. i, p. 466*].

The ore deposits of Colorado are confined to the region of the Rocky mountains, lying thus between the prairie country of the eastern half of the state and the plateau country of the west. The centers of most active mining are in and about Boulder and Gilpin counties in the northern part of the state, Lake and Pitkin counties in the central part, and San Juan county in the southern part. The central part is pre-eminently the area of large lead deposits, fully three-fourths of the product thus far having come from Lake and adjacent counties. The ores of almost all parts of the state, however, have lead associated with them in some form or other. These lead ores we will now briefly describe by counties, in the order of their importance as lead producers in the Census year 1889.

Lake County.—In this county are situated the famous Leadville mines, which have been of such prominence in the mining world during the past 20 years, and which have been rendered classic by Emmons' well-known monograph [*78*]. These deposits furnish all but a small fraction of the whole quantity of lead produced in the county.

Besides being important sources of lead, the bulk of the precious metals of the state have also been produced from them.*

The ores consist principally of cerussite, galena, anglesite and pyromorphite; zinc occurs as calamine or smithsonite, and, at great depths, as zinc blende. In some mines there is practically no zinc, while in others it renders the ores unmarketable [*118, p. 36*]. All lead ores carry a large percentage of iron and manganese. The silver occurs generally as chloride and bromide, associated with calcareous and magnesian limestone; this is present in much greater quantities in the galena than in the cerussite. Gold occurs free, but only in minute quantities in the ore deposits, though it has been obtained in large quantities from the placers of the gulches traversing the rocks containing these ores; it is most frequently found in siliceous beds. The cerussite constitutes the bulk of the surface, oxidized or carbonate ores, which are now largely exhausted, while the galena is encountered at depths. Little or no zinc is found associated with the surface ores, but occurs chiefly with the galena and mainly in the form of calamine.

The gangue of these ores is principally silica, clay and dolomitic lime-sand; with the carbonates are also the hydrated oxides of iron and manganese; according to A. A. Blow [*22, p. 169*], barite is rarely found.

The contents and average value of the ores is indicated by the following results of analysis of a small sample representing 1000 tons, in which were included the product of every mine in the Leadville district [*139, p. 123*]:

	Per cent.		Per cent.
Lead oxide	25.77	Silver	0.31
Ferrous oxide	0.89	Silica	22.59
Ferric oxide	24.86	Alkalies	0.98
Manganese oxide	4.03	Sulphur	0.90
Alumina	3.99	Carbon dioxide	5.58
Lime	2.36	Chlorine	0.09
Magnesia	3.04	Moisture	5.58
Arsenic	0 01		101.00
Antimony	0.02		

Traces of gold, zinc and copper also occur.

*Emmons, writing in 1882, states that Lake county furnishes three-fourths of the precious metals produced in the state [*83, p. 76*].

The rocks immediately associated with the ore deposits are Cambrian quartzites, overlain by Silurian dolomites and siliceous limestones, and by Lower Carboniferous limestones or dolomites (known as the Blue limestone), the whole series aggregating 1000 to 1200 feet in thickness. These strata rest upon Archean granite and other crystalline rocks; they are traversed by sheets and dikes of porphyry which are intrusive principally along the bedding planes, but also traverse the beds. The porphyries represent different flows and are consequently of different ages, though they were all erupted during late Cretaceous times and before the uplifting of the sediments. A porphyry of great prominence and importance is known as the White or Block porphyry; this belongs to one of the oldest of these flows; it has an average thickness of 700 feet, and ranges up to 1500. The Gray porphyry is a younger flow, also closely related to the ore deposits. It is found traversing the White porphyry.

Between Cretaceous and Tertiary times, the region was subjected to great movements and disturbances, which resulted in much folding and faulting of the rocks in a northwest to southeast direction, parallel to the adjacent Mosquito mountain range. Between the time of injection of the porphyries and the time of this uplifting, the mineral deposition took place. The main ore body is confined to the Blue or Lower Carboniferous limestone. It was believed to lie principally along the contact of this limestone with the overlying White porphyry, and Emmons reasoned largely with this understanding. During recent years, however, as deep mining progressed, ore bodies were found to extend in and through the whole body of the limestone. They continued to preserve certain recognizable relations to the porphyry dykes, though not in contact with them [*23, p. 72*]. In this limestone, the ore exists in lenticular masses or chambers, known as chutes, which are connected by contracted passages. The presence of the ores in the limestone is due, according to Emmons, mainly to physical and structural conditions, and because the porphyry is intrusive in it; the age of the rock is of no significance, and its composition is of minor importance [*78, pp 540–543*]. The ores have been derived, according to Emmons, from the porphyries by leaching and replacement of the Blue limestone through metasomatic interchange. He concludes that they were deposited from aqueous solutions as sulphides, not later than the Cretaceous period; that the solutions followed natural water channels such as bedding planes, joints and cleavage openings.

Emmons' theory, as advanced in his report, was contrary to the views that had hitherto been expressed by the authorities on the origin and mode of accumulation of these ores; and, further, it was contrary to the more generally accepted theory of formation of ore deposits in general. It met with opposition at the start. It was attacked by Professor Newberry [*156, p. 329*], who advocated the derivation of the ores from below by heated water, and their deposition in pre-existing cavities. It was criticised by Le Conte [*140*], who also supported the theory of the derivation of the ores from below. More recently Mr. A. A. Blow [*22, p. 145*], arguing from the results of developments since Emmons' investigation, again maintains that the solutions came from below, and that they followed the courses of the gray porphyry dikes. Notwithstanding the weight of the opposition to Mr. Emmons' views, nothing convincing has been developed which seriously impairs the value of his conclusions as to the source of the ore. His interpretation of the structural and stratigraphic geology of the region continues to hold good, with great credit to the character of his work. Perhaps the weakest point in his discussion of these ores is the explanation of the chemical process by which they were formed, as was pointed out by Dr. R. W. Raymond several years ago [*180, pp. 249 and 339*].

Further, the argument for the derivation of the ores from the porphyries is not so well sustained as could be wished; if from that source it is difficult to understand how the porphyries present such an unstained and unleached appearance; why there is a total absence of ore bodies in the porphyry itself; why unaltered beds of limestone frequently exist between the White porphyry and ore bodies; why there are large large bodies of porphyry with no ores associated with them.

Among the principal mines of the Leadville district, are the Crysolite, the Little Pittsburg, the Little Chief and the Annie mines on Fryer hill; the Carbonate, the Yankee Doodle and the Crescent mines on Carbonate hill; the Smuggler, the Rock and Dome, the Silver Cord and the Minnie mines on Iron hill.

Outside of the Leadville district is the Homestake mine, in the northwestern corner of the county, which was developed before the discovery of the silver ores at Leadville [*78, p. 77*]. Here is reported to be a rich body of argentiferous galena in Archean gneiss.

Pitkin County.—The well-known Aspen mines occur in this county, and are the second largest producers of lead in the state. The ore is

similar to that at Leadville, and the manner of its occurrence also. It consists principally of a fine-grained galena, rich in silver. The carbonate of lead, or cerussite, as at Leadville, occurs near the surface, while the sulphides are found at greater depth. Iron pyrite is almost entirely absent in the ores themselves [*135, p. 75*], while barite is common, and in places is so abundant as to impair their value. Silver occurs as silver glance and as chloride. A stain of copper carbonate frequently characterizes the richer ores. Their estimated average contents is given by Mr. W. E. Newberry as follows [*157, p. 277*]:

Silver, 55 oz. per ton ; lead, 5% ; barite, 12·15%.

The ore bodies occur here, as at Leadville, in disturbed limestone and dolomite beds of Lower Carboniferous age, which have an aggregate thickness of about 400 feet. The dolomites exist largely as lenticular bodies, and both Emmons and others conclude that they are in large part secondary [*135, p. cxxi*], [*102, pp. 164 et seq*]. In this respect the conditions are different at Leadville, where the dolomite is thought to have been originally deposited as such.

The strata are traversed by intrusive porphyry and are much faulted. The intrusion of the porphyry probably preceded the faulting, but the ore deposition is considered to have followed both the intrusion and the principal faulting.

The ore bodies are of irregular shapes and grade into the country rock, evidently resulting from the replacement of the limestone; they are most frequently found along the contact between the dolomite and limestone beds, and they extend thence into the body of the rock. They are also found along fault crevices, and, thence, Henrich infers [*102, pp. 182, 202, 203*] that these crevices served as channels for the flow of the solutions. The ores are seldom found in actual contact with the eruptive rocks, although they are probably derived from a great mass of porphyry which overlies the limestone, and which is shown by analyses to contain appreciable quantities of silver and barite [*135, p. 83*]. They occur throughout the whole thickness of the Lower Carboniferous beds, though, according to Henrich [*102, p. 215*], they are less abundant in the lower beds, and the best ore horizon is between 50 and 200 feet from the top.

Among the principal mines are and have been the One Thousand and One, the Spar, the Durant, the Washington, the Emma, the Vallejo, the Aspen, the Ingersoll and the Little Percy.

Chaffee County.—The Monarch district in this county was formerly a large producer of lead ore. The ores occurred in chambers in limestone, some of great size. They were found near the surface and hence easily mined. The chief producers were the Madonna, Eclipse and Silent Friend. The ore was mostly carbonate of lead; some unaltered galena and a little anglesite were found. In the ores of the Madonna mine, the lead contents varied from 20 per cent to 45 per cent, and the silver from five to twelve ounces per ton [*195, vol ii, p 393*].

Park County.—This county, though ranking only 13th in the production of lead in 1889, is immediately east of both Lake and Chaffee counties, and will hence receive notice here. The principal lead-producing mines are along the eastern slope of the Mosquito range, near the western boundary, and opposite Leadville and the adjacent country. The ores are similar to those of Leadville, consisting of argentiferous galena at depths and carbonates near the surface; barite is a common gangue; pyrite is also found, but is generally in a much decomposed condition, giving rise to hydrated oxides of iron. The ores occur in Silurian and Lower Carboniferous rocks, traversed by eruptive porphyries. These latter are considered the sources of the ore. The intrusive porphyry and the amount of ore diminish southward along the Mosquito range. The principal mines of this portion of the county are the Moose, the Russia, the Hiawatha, the Dolly Varden, the Fannie Barrett, the Orphan Boy and the Sacramento [*83, p. 75*.]

In the northeastern corner of the county, in the Hall Valley and Geneva districts, are a number of mines which are in continuation of the Clear Creek silver bed. The ores are found in veins of pegmatite traversing Archean gneiss. In the Whale lode, which is one of the principal veins, are bunches of galena in a gangue composed chiefly of barite [*12, p. 560*].

Gunnison County.—The lead product of this county, according to the Census figures of 1889, gave it the rank of 10th in the state. It borders Chaffee county on the west, and, though some of its ores are dissimilar in their mode of occurrence to the Leadville type, some of the deposits are approximately the same. The deposit of the Golden Cup mine, near Alpine pass, is one of these, the ore being found in Carboniferous limestone. It consists of argentiferous carbonates and also of oxide of copper. Part of this county, in the vicinity of Elk mountains, has been subjected to great disturbances since Cretaceous times. Eruptive quartz porphyry or diorite has forced its way through

the sediments in dikes, or spread itself out between them in laccolite masses. This, with other phenomena observed here, is considered to indicate a region peculiarly favorable for metallic veins [*135, p. cxvii*].

The San Juan Region.—This region has taken its name from the San Juan mountains which traverse it. It includes as lead-producing counties, San Juan, Ouray, San Miguel, Hinsdale and Dolores counties. Of these, San Juan county ranked 4th as a lead producer, and the others 7th, 12th, 14th and 16th respectively in the order of their naming. In this region we find great bodies of Tertiary and older eruptives. These, and especially the latter, are traversed by immense vertical veins of hard bluish quartz. These veins also occur in Archean granite and gneiss. At Rico, ores occur between beds of Carboniferous limestone at their contacts with intrusive igneous rocks [*135, p. cxxxiii*]. Two sets of veins have been recognized in this region, one running in a northwest to southeast direction, which includes the greatest number; the other at right angles to this. The ores consist principally of argentiferous galena, gray copper, and bismuthinite, with ruby silver, native silver and zinc blende. The gangue is a chalcedonic quartz often banded and sometimes with barite.

Among the more interesting deposits are those of Red mountain in Ouray county [*80, p. 139*]. Here the ores are found in cavities or chimneys in andesite, which range in size up to 50 feet in largest dimensions. They were connected by irregular passages which branch out and increase in number toward the surface, but diminish with depth. The secondary ores are principally carbonates of lead and iron, with oxides and sulphates. Zinc blende occurs in botryoidal masses. These ores occur in caves attached to the walls, or in beds of clay or sand. They are richer than the sulphide ores. Normally, the inner walls of these chimneys consist of a quartzose rock which grades into andesite. Some portions of the rock are heavily brecciated. According to Emmons [*80, p. 144*], these chimneys are of elliptical outline, the longer axis corresponding to the main system of fracture, and the ore solutions have replaced the country rock between these fractures, sometimes removing it entirely, elsewhere leaving a siliceous skeleton.

The Boulder County District.—In this district we include Boulder, Gilpin and Clear Creek counties, all of which are lead producers, the last two being 8th and 6th in the state respectively, while the first was 18th. The amount of lead these have produced is thus not very great, and the ores are valuable chiefly on account of the silver contents.

Boulder county is principally known by its telluride ores [*83, p. 66*]. The veins are principally pegmatite or coarse granite, traversing Archean granite. They carry pyrite, tellurides, silver and gray copper. In the Ward district, they carry free gold, while in the Caribou district are rich argentiferous galena ores which occur in gneiss near dikes of eruptive diabase [*135, p. xcix*]. The veins stand at high angles and are often very wide, but the rich ore is confined to streaks in them, and is not continuous. The pegmatite vein material is considered to be a product of the alteration of the country rock, in which the metals have been deposited from solutions, being originally leached from the adjacent rocks also. Ore impregnations are also found along the contacts between the granite and the rocks erupted through it; also along faults or joint-planes in the country rocks. Ore bodies sometimos occur in chimneys or pockets. Two prevalent directions of the veins are recognized, one set running from east to west, the other from northeast to southwest.

Gilpin county immediately joins Boulder county on the south. The country rocks are Archean granite and gneiss, penetrated by felsite and quartz porphyry dykes. The veins are like those of Boulder county. The ores are principally iron and copper pyrite, with very little galena and some zinc blende. They all carry more or less gold, but are difficult to mill.

Clear Creek county is one of the largest silver producers of the state, besides being a contributor to the lead production. The geology and manner of occurrence of the ore are similar to those of Gilpin county, which it adjoins on the south. The veins are here frequently along porphyry dykes. The ores are silver-bearing, and are derived from argentiferous galena and gray copper.

Summit and Eagle Counties.—Summit county ranked 5th among the lead-producing counties of the state, while Eagle was 9th. Ores occur here in rocks of various formations, from the Archean to the Triassic. Sheets of eruptive rocks traverse these strata, and have metamorphosed and faulted them. At the McKay mines, argentiferous galena and lead carbonate are found between sedimentary rocks and overlying porphyry. At the Monte Christo mine, is galena and zinc blende in Silurian quartzite. The ores of the Ten Mile district are in Carboniferous limestone, and consist principally of pyrite mixed with blende and argentiferous galena. The ore is a replacement of limestone and extends irregularly to depths in it. The bodies are large, but of

low grade and refractory. An important mine of this district was the Robinson. Similar ore, under similar conditions, occurs at Elk mountain, though at a different horizon. On Eagle river, near Red Cliff, deposits of agentiferous galena and cerussite are also found in limestone, associated with White porphyry; the limestones are probably of Carboniferous age. Mines here produced large quantities of ore in the early eighties; in 1883 and 1884 nearly 4000 tons of lead were turned out per annum [*195, vol. ii, p. 390*].

The remaining lead-producing mines which deserve notice are in the southern-central portion of the state, in Fremont, Custer and Saguache counties. These ranked respectiuely 11th, 15th and 17th in their product of lead. We have been unable to find any description of the deposits of Fremont and Saguache counties, and therefore conclude with a few remarks on those of Custer county. The principal mines of this county are near the towns of Rosita and Silver Cliff. The rocks consist of Archean gneiss, broken through by diabase, andesite and rhyolite.

Ore deposits of several types occur. Among the most interesting are those at Bassick and Bull Domingo. Emmons describes these deposits in his report of the 10th Census [*83, p. 80*], and later he gives an explanation of their origin [*95, p. 833*]. The ore is found in somewhat irregular bodies, without definite boundaries. These bodies consist of rough and partially rounded fragments of the adjacent country rock (a hornblendic gneiss), which are coated with different ores in layers one-eighth to one-fourth of an inch thick. These are principally sphalarite and argentiferous galena. The spaces between the fragments are filled mainly with kaolin. The Bassick mine is an irregular opening of square or lozenge-shape, from 20 to 100 feet wide, and open to a depth of 1100 feet. It occurs in andesite breccia. The included fragments range in diameter up to two feet, and decrease in size from the center outward. A peculiar fact is that small fragments of charcoal are found in depths of nearly 800 feet in these deposits.

Emmons classes these as chimney deposits which have resulted from the crushing and decay of the country rock between fracture planes. Aqueous solutions penetrating these crushed masses have dissolved and reduced the size of the fragments and deposited the ores around them. The Bull Domingo is now the largest lead producer in the district; the concentrates are shipped to Leadville.

Another type of deposit occurs near Silver Cliff, consisting of an irregular impregnation of the country rock. Among other ores found here is massive cerussite.

Conclusion and Statistics.—The great extent, variety and richness of Colorado's ore deposits would tempt one to dwell, even longer than has been done, upon their description, did the limitations of this report permit it. This prominence of the state as a lead-producer has led us, however, to give a somewhat full description of the more important lead-bearing deposits. The yield from these has been enormous in the past, and, though not increasing as it did in past years, the state still holds its pre-eminence as a lead-producer.

The mining of lead and silver ores in the state is of comparatively recent date; about the earliest was at the Georgetewn mine in 1866 [*134, p. 589.*] Gold mining, especially in placer deposits, was prosecuted nearly ten years before the war; but the value of the silver carbonates was not recognized until early in the seventies. At Leadville, what may be considered the first discovery of the famous carbonate deposits was made in 1874, though actual mining was hardly begun before 1876.

In the table of productions by states given in the next chapter, the amounts of lead produced in the state from 1873 to 1892 are shown. The tables of the following page give the productions of Leadville, and the distribution of productions during the Census year 1889. This last table conveys an idea of what proportion of the total output has been supplied by the different mines:

PRODUCTION OF LEAD IN LEADVILLE.
From Mineral Industry, Vol. II, p. 390.

	Tons.		*Tons.*
1877	835	1885	36,100
1878	6,000	1886	48,500
1879	22,500	1887	47,000
1880	34,000	1888	45,500
1881	39,000	1889	50,500
1882	45,000	1890	*35,000
1883	*60,000	1891	*32,000
1884	*53,000	1892	22,211

* Estimated.

PRODUCTION OF LEAD IN COLORADO BY COUNTIES FOR CENSUS YEAR 1889.

[*208, p. 163.*]

	Tons.		*Tons.*
Lake	50,492	Fremont	310
Pitkin	7,132	San Miguel	308
Chaffee	3,307	Park	278
San Juan	1,787	Hinsdale	258
Summit	1,597	Custer	233
Clear Creek	1,539	Dolores	168
Ouray	1,333	Saguache	62
Gilpin	1,013	Boulder	9
Eagle	492	Total	70,788
Gunnison	467	Total value	$2,101,014 31

NEW MEXICO.

New Mexico, though not ranking among the first of the lead-producing states of this region, has yielded during the past ten years an average of about 5000 tons of lead annually. The ores are argentiferous galenas and carbonates. Considerable quantities of zinc ore are also found at other localities, and have been mined to a limited extent. The most important mines are in the southwestern quarter of the territory, in Socorro, Sierra, Dona Ana and Grant counties. Small amounts have also been mined in Lincoln, Santa Fe and Taos counties.

Socorro County.—In this county are the well-known deposits of the Magdalena mountains, including the Kelly mines and others. The rocks, according to Emmons [*83, p. 102*], consist of slates, limestones and quartzites, resting on gneiss and traversed by porphyritic eruptions. The ore consists at the surface chiefly of lead carbonate and of calamine and anglesite. Lower down, galena and blende are found. In 1887 these ores were reached at the Kelly mines, but at the same time new deposits of oxidized ores were discovered. The ores occur in lodes along the contacts between the country rocks and the porphyry. The Juniata was one of the largest, and had a maximum thickness of 65 ft. During recent years, the ores of this district have averaged about 25 per cent of lead and 8 ounces of silver [*195, vol. ii. p. 398*]. Smelters are erected at the town of Socorro, which turn out almost all of the lead in the territory.

In the Negretta or Black mountain range of this county, lodes of lead and zinc ores are also reported by Silliman [*142*].

Grant County.—The lead ores of Grant county are principally along the western slope of the Mimbres range of mountains, east of Silver City. According to Emmons, the deposits are argentiferous lead ores in Paleozoic limestones, which generally follow the bedding planes.

In the Burro mountains, west of Silver City, are also argentiferous lead ores in Paleozoic limestones.

In the Santa Rita mountains, east of Silver City, such ores occur in Carboniferous limestone.

The Cook's Peak mines are at the extreme eastern edge of the county, about 10 miles north of Florida. They have produced a good deal of ore during recent years. The deposit occurs in fissures in porphyry. The ore is galena, which, in the past two years, has averaged 43 per cent of lead and 61 ounces of silver [*p 195, vol ii, 398*].

The Hanover zinc deposits are also in this county. They were formerly worked for copper, and only during the past few years have efforts been made to utilize the zinc ores. They are at present owned by the Mineral Point Zinc company of Wisconsin. They are located about 20 miles northeast of Silver City. According to Mr. W. P. Blake [*18*], the country rocks are gray and white Paleozoic limestones, probably of Lower Carboniferous and older age. These rest upon Archean granites and are traversed by dikes.

The ores are principally smithsonite, with some calamine. They are generally found in proximity to the dikes. They occur in crusts lining cavities, or in masses, which occupy irregular openings between the beds of limestone, or fill caverns. The oxidized ores have replaced the limestone. The best grades carry from 35 to 38 per cent of zinc. Large deposits of blende are found, from which the carbonates have been derived. These primary ores consist of a mixture of blende with amphibole, garnet, epidote, specular iron and pyrite, which are disposed in regular layers, conforming in a general way to the wall rocks of the deposit. The form of these deposits of blende is lenticular. Galena is generally absent.

Comparatively small amounts of these zinc ores have been mined as yet. Transportation facilities are poor, and difficulties in the separation of the blende from the heavy garnet and also from the pyrite have hindered the development. Fuel is also scarce.

Sierra County.—The Lake Valley mines, which are generally credited to Dona Ana county, really belong in this county, owing to recent changes in boundary lines. They are located in the valley east of the Mimbres range of mountains. The ore bodies occur in limestones which dip eastward. These limestones, says Emmons, contain Waverly fossils, and are thus probably Lower Carboniferous. The ores consist of argentiferous galena and cerussite, and occur along the bedding of the limestone and along the contacts between it and eruptive rocks. Much iron and manganese are associated with the oxidized ores. They apparently resemble the Leadville deposits.

Dona Ana County.—The Lake Valley deposits, as stated above, were in the past included in this county, which accounts for some of the large shiptments credited to it.

In the Organ mountains, about 10 miles west of Las Cruces, are argentiferous lead ores which have yielded 36 per cent of lead and 1.6 per cent of silver [*181, p. 412*].

Santa Fe County—In this county there are a number of deposits of siver-lead ores which were formerly worked. The mines in the Cerrillos hills worked many lodes containing such ores, in some of which zinc blende is quite abundant.

Mining of lead ores in the territory, as in other western states, is not much over 25 years old, though deposits were worked for silver long ago by the Jesuits, probably before 1680. In 1867 the silver-lead ores of the Magdalena mountains were discovered by a California miner.

Productions.—The production of lead in the territory is given in the general table of the next chapter. The production by counties during the Census year 1889 is shown below.

	Tons.	Value.		Tons	Value.
Dona Ana	1,028	$35,916	Sierra................	339	$9,536
Grant...............	1,618	44,623	Socorro.............	1,187	57,859
Lincoln..............	30	600	Taos................	10	200
Santa Fe............	550	22,020		4,762	170,754

Zinc ores have been mined only quite recently. In 1889, 140 tons were shipped; in 1891, 700 tons. Nothing was produced in 1892. Up to January, 1894, according to Mr. Blake, 1355 tons of ore had been shipped altogether, by rail from Hanover.

TEXAS.

Lead ores in Texas are confined to the mountains of the Trans-Pecos region and to what is known as the Central Mineral region, which is a tract about 75 miles square, with Llano county in the center. In neither region are these ores abundant, however, and such mining as has been done was quite rudimentary. In the Trans-Pecos region some zinc ore also is found, but in the central region it is almost entirely absent. Mr. E. T. Dumble, the State Geologist [*73, p. lxv*], speaks of the Sam Houston Mining Co.'s mines as the most extensive lead diggings. These are situated on the Riley mountains, in Blanco county. The deposit is in veins and the ore is galena; the workings are 160 feet deep.

In the Beaver Creek district, in Burnet county, are a number of developments made in search of lead ores. Comstock [*72, p 340*] describes the deposits as consisting of galena in veins or dikes in Cambrian, dolomitic limestone. The gangue of the vein is not quartz, but ferruginous sand. Similar deposits occur near Hye postoffice, in Blanco county [*73. p 384*].

In the Trans-Pecos region, the principal developments are in the Quitman mountains, southwest of Sierra Blanco, between that place and the Rio Grande river. These mountains are composed chiefly of granite and intrusive porphyries. Here, the Ellbrook mine, referred to by Streeruwitz [*71, p. 33*], is on the contact or crystalline limestone and granitic porphyry. The gangue is spar and the ore galena. The shaft was 67 feet deep when visited. Openings have been made at a number of other points, disclosing veins of argentiferous galena. Zinc ores are found at greater depths, and they are also often argentiferous.

The Bonanza and Alice Ray mines have shipped some good ores to El Paso. These contained about 30% of lead, 25% of zinc, 20 to 30 ozs. of silver, and a trace of gold. The presence of zinc so increased the smelting charges that almost all profit on the ore was consumed. A good deal of argentiferous copper ore is found here [*73, p. 233*].

In the Carizo group of mountains, composed principally of crystalline schistose rocks, near the eastern border of El Paso county, prospecting has revealed the presence of anglesite and other lead ores.

In the Chinatti mine, in Presidio county, argentiferous galena in fissures or veins has been found at the Spencer mine; also, in the Shafto mine, both galena and lead carbonate have been produced.

UTAH.

The ore deposits of Utah contain, besides the precious metals gold and silver, compounds of lead, copper, iron and zinc. The lead ores are very abundant, and have been sources of large productions for over 20 years. The zinc ores are entirely accessory and are not sources of supply. The deposits occur principally in the western part of the state, along the western slope of the Wasatch mountain range, on the edge of the plateau country; but they are also found among the subordinate mountain ranges of the Great Basin, still farther west.

The stratified rocks of this region are pre Mesozoic, though lake deposits of Tertiary age exist in places. These clastic rocks are underlain by Archean granite, and are traversed by Mesozoic diabase and diorite, and by Tertiary or post Tertiary andesite, rhyolite and basalt.

A series of granite-porphyries is also recognized [*83*, *p. 39*]. The geology of the mineral region is thus similar to that of the Great Basin of Nevada, which adjoins it to the west. Along the western side of the Wasatch range, a great fault traverses the rocks. The movement producing this fault apparently began as early as the Archean era; it was renewed at later dates, and there is evidence that it is even now in progress. This line of fault is thought by Becker [*83*, *p. 39*] to have had an important influence upon the ore deposits. The abundance of these ore bodies along the western side of the Wasatch range certainly bears this out. The prevailing type of deposits are bodies of argentiferous lead ore in limestone, occurring in chambers or "pockets," as at Eureka, in Nevada, next described. Veins in slate and quartzite also occur, but lead ores do not prevail in these. The age and origin of the various ores is not yet definitely determined. In general terms, they are held to be principally due to solfataric action, which accompanied the eruption of the massive rocks. They would thus be of corresponding age and of similar origin to the Nevada ores.

The mining districts and mines of this State are very numerous; almost every county of the western half contains such. A detailed description of these districts is contained in the report of Mr. E. B. Huntley [*117*], which forms a part of Vol. XIII of the Tenth census. A separate description of the many districts and mines cannot, of course,

be attempted here; reference will be made only to prominent deposits of lead-yielding ores.

Salt Lake County includes several of the most important mining districts in the State. These are the West Mountain Mining district, including Bingham canon, the Little Cottonwood, with the Emma mine, and the Big Cottonwood districts. West Mountain district is on the eastern slope of the Oquirrh mountains, on the eastern border of the Great Basin. The mines are in canons only three miles from the summit of the range. The principal of these is Bingham canon; others are Barney's, Copper gulch and Butterfield canons. In each of these are a number of mines. The country rock consists of Carboniferous limestone and quartzite, faulted and traversed by dikes and masses of andesite and granite-porphyry. The ore deposits occur both transverse to and along the bedding. In the porphyry, some narrow veins are also found. The ores frequently follow altered zones along the contact between the limestone and quartzite. The bodies of these zones are of irregular shapes, and the contact with the surrounding rock is not sharp, the country rock being at times impregnated with the ore [*137, p. 25*]. The larger bodies of ore are generally connected by crevices or pipes.

The great lead-producing mines of this district are in a large bedded deposit, some two miles long, dipping 35° to 60° N. W. The ores of this deposit are ochreous, siliceous and pyritiferous, carrying galena and zinc blende. These last constituents are converted to carbonates in the oxidized surface ores. The amount of blende is quite large in places, so much so as to make the smelting of the ore difficult. The Jordon mine is the principal one in the Bingham canon. According to Mr. Huntley [*117*], 87,000 tons of argentiferous lead ore were produced from this mine between the years 1873 and 1880. The ore body is interbedded in siliceous limestone, is about 200 ft. wide, and dips 30° to 35° N. W. Large horses of limestone occur here. Great bodies of cerussite, anglesite and galena are found along the foot-wall; while along the hanging wall is a thick belt of quartzose gold ore. The best ore averages 40 to 43% of lead. Several other large mines have been opened in this district, in deposits of similar composition and geologic relations. In Butterfield canon, the Yosemite mine is in a deposit of like nature, with high grade lead carbonate ores.

The Little Cottonwood district is famous chiefly on account of the great deposit of the Emma mine. It is located in the eastern part of

the county, near the summit of the Wasatch range, at the head of Little Cottonwood canon. The ores here are perhaps most abundant in the Wasatch limestone of Lower Carboniferous age, but they are not confined to any particular stratum or formation [*84, p. 364*]. The deposits follow pre-existing fissures and cracks. They generally occur near lines of fault, and spread out in lenticular-shaped masses and chambers. The Emma deposit is in siliceous limestone. The principal ore body worked was between a limestone hanging wall and a dolomitic foot-wall, and was, in a general way, conformable to the stratification. The walls contracted both above and below, and the chamber did not extend to the surface. The ore was a soft, brownish red ocher, containing cerussite, anglesite and some manganese. It was very easily excavated. The percentage of lead varied from 30 to 66 per cent. Prof. Silliman [*207, p. 325*] gives 34 per cent as the amount of lead found in an average sample of the ore collected from 82 tons. Much of the ore had no clearly recognized gangue, and was shipped directly in sacks as it came from the mines. The sales of the ore, up to June, 1880, are given by Mr. Huntley as 27,450 tons. Phosphate of lead was not found here, and its general absence from the ores of the Wasatch and Oquirrh mountains is a noticeable fact. The deposit of the Emma mine, like the others of this district, is more recent than the porphyry dikes which traverse the rocks. The ore body is, however, traversed by a fault of later age [*185, p. 338*].

Several important mines in this district, such as the Flag Staff, occur in similar deposits; also in the Big Cottonwood district, especially about Argenta.

In Beaver County, is another important lead-producing district, on the northern end of the San Francisco mountains. Here, the Horn silver mine is the most noted and has been the scene of large operations. The ore was found between a foot-wall of dolomitic limestone and a rhyolite hanging wall. It consisted largely of sulphate of lead, but oxides and carbonate, with silver ores, were also found. Barite occurred as a gangue near the rhyolite. The lead contents varied from 30 to 60%; little or no zinc was present. The deposit is traceable two miles in a direction N. 10° W. The dip is about 70° E. The width, where discovered, was between 40 and 60 feet. Mining has penetrated to depths of 1200 feet or more. The total product of the mine up to the year 1880 is given by Mr. Huntley as 29,380

tons, averaging 35% of lead. After that time, the production was larger, and, at the cessation of operations in 1884, it is estimated that 69,380 tons of lead bullion had been produced [*110, p. 7*]. Large dressing works are being built to treat the low-grade ores. They were nearly completed in January, 1894 [*195, vol. ii, p. 400*].

Several other mines in this county are in similar deposits of lead-bearing ores. Such are those of the Bradshaw and Star districts. The Cave mines of the former are in stratified blue and white dolomitic limestone, which contains bodies of argentiferous, ocherous lead carbonates, in large and small caves or chambers. A vacant space frequently exists between the top of the ore and the limestone roof, and the former is sometimes strewn with detached blocks of limestone, thus simulating some of the Nevada deposits. Ocher sometimes occurs here in the form of hard, massive, botryoidal limonite.

At the Carbonate mine, near Frisco, lead-bearing ore is found partially cementing rounded blocks of trachyte, in a vein some six feet wide. This ore carries from 15 to 20% of lead. The peculiar structure of the deposits is doubtless due, as explained by Rothwell, to the fracturing and partial decay of blocks of eruptive rocks which have fallen into a fissure [*196, p. 118*].

In Tooele County, in the Rush Valley district, on the western slope of the Oquirrh range, are argentiferous deposits in limestone and quartzite of Carboniferous age. The ores occur in bedded veins, transverse to the stratification. The former are 9 to 10 feet wide in the Great Basin mine, and dip about 60° N NE. The best ore averages about 40% of lead. In the Dry Canon district, large bodies of oxidized ore in limestone occur in chimneys and chutes. The Hidden Treasure mine was one of the most important of these. The ore of this deposit contained about 33% of lead. Other prominent mines here were the Chicago, Mono and Kearsarge. In the Ophir and other districts of this county other such deposits have been worked.

In Utah County, in the American Fork and Provo districts, are also deposits of silver-lead ores, in large bodies in dolomite. They contain frequently as much as 40 to 54% of lead.

In Piute County, contact and bedded deposits of similar ores are found between limestone and quartzite, carrying 35% of lead.

In Juab County, argentiferous galena and other lead compounds occur in the Eureka Hill deposits of the Tintic district. Such ores

are also found in the East Tintic, Dugway and Mount Nebo districts. In Wasatch, Box Elder and Weber counties, a few deposits containing lead ores are also known to exist.

In Summit County, the famous Ontario mine has lately supplied considerable quantities of lead. The deposit, however, is not of the class that carries a preponderance of these ores. The walls are in the main, quartzite. The ores occur in a vein which averages perhaps 8 ft. in thickness, though ranging up to about 30 ft. The gangue consists of quartz, and in this are zinc blende, galena, tetrahedrite and pyrite, with some horn silver and copper carbonate. The average contents of the ores of this and other Park City mines is about 30% lead.

The great deposits of the Silver Reef district, in Washington county, though of interest and value, cannot be classed as sources of lead or zinc. Little or none of the compounds of these metals are found there.

History and Statistics.—Utah has been a mining state for nearly 30 years. Salt Lake was occupied by the Mormons in 1847; but these people devoted most of their attention to agriculture. They claim, however, to have mined a few tons of lead ore in Beaver county, in 1861 and 1863. In 1863, the Jordon mine, of Bingham canon, was located. In the following year the Emma, and other deposits of the Cottonwood district, were discovered; but the great Emma lode was not opened until nearly 1870. In 1870, the first efficient smelter was erected, not far from Salt Lake, and a period of great excitement in mining affairs soon followed. In 1872, the Ontario deposit was discovered. In 1875, the Horn silver deposit, in Beaver county, was disclosed [*117, p. 406*]. By 1875 the deposits of the Emma mine, which, up to that time, had been the principal sources of lead ore, were exhausted. In 1885, the Horn silver mines closed down; but operations are resumed there now.

Figures of production of lead in this state have been gathered almost ever since the mining of the deposits began. The annual productions of the whole state are given in chapter VI. The following details have been derived from the several volumes of the Mineral Resources of the U. S., from the Mineral Industry for 1892, and from the Eleventh census:

DETAILS OF LEAD PRODUCTION IN UTAH.

Yrs.		Tons.
1881	Horn Silver	8,171
1882	Horn Silver	16,002
1883	Horn Silver	14,970
	Bingham District	9,500
1884	Horn Silver	12,400
1885	Principally from Bingham, Tintic, Park City and Beaver district	23,000
1886	Stockton mines heavy producers; Bingham district also large	19,000
	Ontario	1.882
1887	Ontario	2,015
	Bingham district (about)	8,000
	Tintic district large producer	
1889	Beaver county	4,487
	Juab "	130
	Piute "	70
	Salt Lake "	4,794
	Summit "	5,641
	Tooele "	1,483
	Wasatch "	30

NEVADA.

The state of Nevada, though at present comparatively a small producer of lead, has been in the past one of the great lead states. Moreover, her deposits have received as much, if not more, study than those of any other western state, and as they are of an extremely interesting and instructive type, they deserve a somewhat lengthy notice here. The mining districts are among the subordinate mountain ranges of the Great Basin, which extends from the Wasatch mountain range on the east to Sierra Nevada on the west. The area of greatest production lies between the 39th and 40th parallels.

The rocks of this area include massive granites of the Archean, Paleozoic, Mesozoic and Tertiary clastics, eruptive diabases and diorites of post-Jurassic age, and andesites, rhyolites and basalts [*83, p. 30*] of Tertiary and Quaternary ages.

The ore deposits of the state are important chiefly for their richness in precious metals; lead, copper, zinc and other base metals occur, however, associated with these, but only in a few districts are smelting lead ores found.

Comstock Lode.—The famous Comstock lode is near the extreme western edge of the state, at Virginia City, in Storey county. The ores of this lode contain comparatively little lead or zinc,* but prin-

*Analyses of these ores show the lead contents to vary from 4 to 6 per cent, and the zinc contents from 11 to 16 per cent [*95, p. 80*].

cipally native gold and silver, with sulphides of silver and antimony. The gangue is mainly quartz, and in this gangue the ore is found in sheets or lenticular masses, known as "bonanzas." The lode is several hundred feet wide near the center, but tapers toward the ends, and is narrower at depths; it is largely filled with horses of country rock, between which the quartz gangue and the ores are found. The total length traced is about 4 miles. The rocks consist of eruptives of post-Jurassic and Tertiary ages. The mines produced, in the 21 years preceding the year 1880 over $306,000,000 worth of gold and silver. They reached depths of over 3000 feet, and galleries aggregating 185 miles in length were excavated [*156*].

Eureka Mines.—The deposits of the Eureka district in Eureka county were the great sources of lead in the state. The principal mines are situated on Prospect mountain, and here they are concentrated on the northern spur, known as Ruby hill. Work was not begun in these mines until the latter part of the year 1869. By the year 1882, $60,000,000 worth of gold and silver had been produced and 225,000 tons of lead. These ore deposits have been studied by a number of eminent geologists and mining engineers, and their relations are well understood. The foremost report upon these ores is the monograph of Mr. J. S. Curtis, published in 1883 [*54*]. Quite recently, Mr. Arnold Hague's report on the Geology of the Eureka district has been issued [*93*].

The rocks represented in the Eureka district are of Cambrian, Silurian, Devonian and Lower Carboniferous ages, and aggregate about 30,000 feet in thickness. The ores are found in Cambrian, Silurian and Devonian strata, extending thus through a column 17,000 feet thick. None are found in the Carboniferous strata. By far the greatest number of productive deposits have been in the lower Cambrian rocks. The reasons for this, as Mr. Hague puts it, lie in the orographic and structural conditions, and not in the facts of the age or composition of the rocks. Between the close of the Carboniferous and the Jurassic period, this region was much disturbed, and the rocks were flexed and traversed by fissures and faults which are generally parallel to the axes of the folds. Subsequently, soon after the Tertiary period, there were eruptions of andesite and rhyolite, which augmented the displacements and doubtless expanded the fissures in some places. The ore deposition followed this period of eruption, and the ore bodies are closely connected with the rhyolite dikes.

The main ore body or lode, if it may be called such, of Ruby hill and Prospect mountain, consists of a wedge-shaped mass of crushed limestone, which lies between what is known as the Ruby Hill fault or Main fissure on the northeast, and the so-called Secondary fissure or quartzite contact on the southwest. This zone of crushed rock is over 800 feet wide at the surface, but tapers out in places at depths of about 1000 feet. Throughout this zone the ore bodies are found. The ore fills crevices and interstices between the fragments and masses of the limestone, and also occupies great chambers 50 feet and more in diameter. These great chambers are generally completely filled with ore, excepting for a small cavity near the top of the body, or an occasional pillar of limestone traversing it. Branches or pipes of ore lead off in all directions. There is no well-defined boundary in many cases. They are distributed without any regularity, and are generally connected with a fissure, though this connection is not always seen.

The minerals of the ore consist principally of a dark gray, often black galena, which is generally rich in silver, but somewhat low in gold, of anglesite, cerussite, mimetite, wulfenite, pyrite and arsenical pyrite, limonite, blende, calamine, calcite and argentite; quartz is found in cavities of the limestone, but is not an important constituent. Clays of various kinds, and steatite and talc are occasionally found. The siliceous ores generally contain most gold. Galena is not abundant, and the carbonates or oxidized ores extend here to depths of 1300 feet. Limonite, derived from pyrite, is the principal gangue of the Ruby hill ores. The blende is generally found in the lower workings, calamine being met with near the surface.

The ores are generally believed to have been derived from a deep-seated source, through solfataric action, accompanied by volcanic energy. Curtis [*54, pp 82-92*] states that no rhyolite near the ore bodies contains sufficient gold, silver or lead to be the source of the ore, though when deeper seated and undecomposed the contents may be greater; assays of the country rock show also too small quantities of the precious metals. He concludes, therefore, that the theory of local segregation is untenable. The ores are probably derived from decomposition by solfataric action of massive rocks, and the solutions were conveyed thence to higher levels by the fissures formed through earth movements and volcanic action. Two main fissures have been referred to, and one of these constitutes the Ruby hill fault. With these, other minor fissures connect. The Ruby hill fault fissure was

originally occupied by a rhyolite dike, but this is now largely decomposed, leaving a clayey residuary product. The ascent of the solutions and the decomposition of the ores probably continued for a long time after the eruption of the rhyolite.

The solutions were probably alkaline sulphides, and the metals were deposited as sulphides in the openings of the crushed limestone. The large chambers or masses of the ore, both Mr. Curtis and Mr. Hague maintain, were formed from the metasomatic replacement of limestone by the ores. The great part of the ore is hence the result of substitution rather than of deposition in open cavities. The conclusions reached by Mr. Curtis are, in the main, in accordance with the opinions held by other authorities. Previously published descriptions of these deposits had generally explained the large ore bodies on the theory of their deposition in pre-existing caves; they described the clay found in the Ruby hill fault as a shale, apparently considering it a regularly interstratified member [*20, 132, 179*]; whereas Mr. Curtis shows it to be the product of decomposition of a rhyolite dike. His conclusions in this particular, as well as concerning the origin of the large ore bodies, seem to be well sustained.

The Eureka district ore deposits are not an isolated class in the state, but others occur like them in the Great Basin. They are, however, the most important so far developed.

Lincoln and Nye Counties.—In these counties are a number of deposits of argentiferous lead ores, associated minerals and their decomposition products, occurring in limestones, which are similar to those at Eureka. The ores are also found in veins traversing metamorphosed quartzite slates. These are not smelting ores, however. The percentage of lead in the Pioche ores is stated to vary from five to sixty per cent [*183 p. 184*].

White Pine County.—White Pine district, in the county of this name, has been the seat of much mining during various periods. Treasure Hill is the principal mining district, and here the ore is found in fissures, contact deposits, and in chambers or in beds parallel to the stratification of the limestone. The mineral contents are chiefly chloride of silver, with about two per cent of lead [*95, pp. 418–420*]. In the Base Metal range, immediately adjoining the Treasure Hill district to the west, the ores contain a much larger percentage of lead. These deposits are thought to be similar in nature and origin to those of the Eureka district.

Elko County.—In the Tuscarora district, silver ores are found, accompanied by pyrite in decomposed eruptives. Small amounts of lead have been shipped from this county during past years.

Esmeralda County.—Ores carrying argentiferous galena in pockets and veins are found in Washington and other districts [*34, pp. 335-337*]. Most of the ores are in metamorphosed slates and schists which are traversed by basalt. They are similar to those of Inyo county, California. They carry sulphantimonides of silver, argentiferous galena, tetrahedrite, and copper, iron and zinc sulphides and pyrolusite in a quartz gangue. The Northern Belle mine was in such ores, mainly oxidized [*83, p. 34*].

Lander County.—Near Austin, in the Reese River district, are a large number of small veins traversing granite, which consist of a quartz gangue carrying silver sulphides, argentiferous galena and blende. The amount of the last two constituents is, however, not sufficient to class these as lead-bearing ores.

In the Galena district of Washoe county and in Humboldt county, small amounts of galena have been found, but they are not at present sources of lead, and little is generally known concerning the character of the deposits.

History and Statistics.—Mining in the state of Nevada is little over 30 years old. The Comstock lode was discovered in the latter part of the year 1858, and mining was begun there early in the following year. The Eureka deposits were discovered as early as 1864, but their value was not determined until 1870, and little was done there before that time. In fact, up to that date, silver-lead ores were regarded as of little value, and the deposits were allowed to lie neglected. In this same year, furnaces for the reduction of these ores were built. Deposits in Esmeralda county were discovered in 1867; those in Lincoln county in 1864; in the Toyabe mountains of Lander county in 1862. In 1869, the ores of the White Pine district first attracted great attention, and that district was the scene of much excitement.

Detailed figures showing the production of lead in this state are not available. From the Eureka district, however, most of the lead ore has been derived, and the largest producers there have been the Eureka Consolidated and the Richmond Mining companies, on Ruby hill. In 1886 the Ruby hill ores were to a great extent worked out, and during recent years the production has fallen off, so that it has now reached almost insignificant figures. The figures of production of the

whole state, given in the table of chapter VI, are derived principally from vol. II (1893) of the Mineral Industry.

Up to the end of 1882, Mr. Curtis states that the total production of the Eureka district had been 225,000 tons. Deducting from this the total production during the years 1877 to 1882 inclusive, leaves 113,333 tons. This represents approximately the amount produced in the Eureka district during the years preceding 1877. In order to be exact, however, we must add to this amount what was produced in other districts during the years 1877 to 1882. Allowing 3350 tons for the total production of these other districts during that period, as well as for the whole period preceding 1877, we obtain 260,000 tons as the total production of the State to date.

The following figures taken from Bulletin 80 of the Tenth Census, show the distribution of production during the year 1889:

PRODUCTION OF LEAD IN NEVADA.

Counties.	*Tons.*	*Counties.*	*Tons.*
Elko	30	Nye	10
Eureka	1489	White Pine	136
Lincoln	330	Total	1995

CALIFORNIA.

California, though not classed as a lead and zinc-producing state, contains extensive deposits of lead-bearing ores, which have been operated on a large scale for the precious metals. These occur principally in Inyo and San Bernardino counties, in the southwestern portion of the State. Such are also known to occur, however, in San Diego, Kern and other counties.

San Bernardino County.—Large argentiferous lead deposits occur near Kingston mountain, in the northeastern corner, in a country rock of dolomitic limestone. West of this, in the Arawatz range, veins and deposits of lead ore, accompanied by gold, silver and copper, have been discovered, and were worked about the year 1880. Difficulties of access and scarcity of water have helped to prevent development [*120*]

In the southeastern portion of the county, near Denby, in the Old Woman mountains, a "large and extensive ledge of carbonate and galena" is described as occurring in "granite and slate formations."

In the Morongo district, in the southwestern part of the county, is the Lawrence mine. Here galena occurs in a vein four feet wide, traversing "granite and micaceous slate," the strike being N. 80° E. In the vicinity of the Oro Grande there is a large number of mines of argentiferous galena. At Galena camp, seven miles west of that place, a vein is reported 20 feet wide, the hanging wall of limestone and the foot-wall of syenite, with a strike N. 20° W.; the ore is principally argentiferous galena and carbonate of lead. Other mines in deposits of similar character have been opened in this vicinity. The Harrison mine is 4½ miles northeast of Oro Grande; the vein is five feet thick between walls of blue limestone; the ore consists of galena and sphalerite carrying silver. The Carbonate mine is two miles east of Oro Grande, on the western slope of the Oro Grande mountains; the vein underlies blue limestone, is 18 to 24 feet thick, has a dip of 45° N. and a strike of 80° E. Different assays of the ore yielded 40 and 57 per cent of lead, 6 and 40 ounces of silver, and, in one lot, $16 worth of gold.

About Barstow, in the central-western portion of this county, a number of developments have been made. At the Stonewall Jackson mine, 6 miles northwest of Barstow, a vein 8 feet thick is reported, containing oxide of iron and carbonate of lead. At the Cleaveland mine, 5 miles northwest of Dagett, the ore runs 26% of lead, 20 ounces of silver; the vein dips 35° E., "hanging wall porphyry, foot-wall decomposed feldspar." Other openings in deposits of similar character occur in this neighborhood.

Inyo County.—This county [*120*, *134*] is the chief source of lead ores in California. Eighty per cent of this ore, as delivered, consists of sulphides, containing some zinc, and often arsenic and antimony. Extensive beds of carbonate are reported to occur in the southern portion of the county, but, like those of northern St. Bernardino, they are very difficult of access, and a scanty supply of water makes their operation difficult. These ores of the county occur either in limestones, or in limestones associated with schists. The deposits are chimneys or bodies of irregular form [*83*, *p 18*].

In the southern part of the county, in the Penamint district and mountains, in the vicinity of Wild Rose spring, there are a number of mines in silver-lead ore. In the Darwin district, adjoining this, occurrences of veins are reported carrying galena and lead carbonate, with gold and silver. Of these, the Defiance mine produced ore carrying

50 per cent of lead, 68 ounces of silver and some gold; the Lucky Jim mine ore assayed 40 per cent lead and 50 ounces of silver. Many other openings in similar ores have been made in this district.

Mines of like character are located in the Cerro Gordo district, on the western slope of the Inyo range.

About Independence, the county seat, are also a number of mines. The Brown Monster is one of these. Here a shaft was sunk 400 feet deep, the vein averaging 6 feet in width, with 12 inches of vein matter next to the hanging wall; the ore assayed 40 per cent of lead and 70 ounces of silver. The St. Carlos mine is another of this group, the ore of which carries 30 per cent of lead, $100 in silver, 12 per cent of copper and a little gold.

Zinc, apparently, does not occur in workable quantities in California. As already noted, it is associated with some of the lead ores of the two counties just described. In addition, small deposits of sphalerite, of no present value, are referred to as occurring in Tulare and St. Mateo counties, in the report for 1882 on the Mineral Resources of the U. S. of the Geological Survey.

Production.—However great the lead-bearing deposits of California may be, the production of lead in the state thus far has been comparatively small. According to the figures of the report for 1883-84 of the Mineral Resources of the U. S., California's production of lead for those years was respectively only 1700 and 1600 short tons; in 1887, the total output from local ores is estimated by the Selby Lead & Smelting Co., of San Francisco, at about 800 tons. In 1889, the state is credited by the same authority with 53 tons of ore only; but in the 10th Annual Report of the State Mineralogist, it is stated that about 3400 tons of lead ore, averaging 47 per cent of lead, were received at the Selby works from January to October, 1890. These works receive and smelt the great bulk of the lead ores of California. The 11th U. S. Census distributes the 53 tons of ore for the year 1889 as follows:

Butte	400 lbs.
Inyo	94,110 "
San Bernardino	12,000 "
Total	106,510

Inaccessibility, scarcity of water, limited population and a blinding search for precious metals are, apparently, the chief factors which have prevented the development and increase of lead production in the state in the past.

ARIZONA.

Arizona produces a few thousand tons of lead annually, incidentally to the smelting of her silver ores. The principal productions are from the southeastern portion of the territory.

In Pima and Cochise counties are a number of deposits in limestone, which consist in large part of argentiferous lead ores. The Tombstone district contains such. The country rocks here are quartzites of probable Carboniferous age, underlain by dolomites and overlain by bluish black limestone. Most of the ore is found in the last mentioned rock [*19, p. 334*]. The rocks are disturbed and faulted and are traversed by dikes of diorite and diabase. The ores occur in vertical fissures, and also in bodies following the stratification of the rocks, which dip to the northeast. Elsewhere in these counties, similar deposits are found, but none have proven of equal magnitude.

In Maricopa and Mohave counties, galena and blende are found, associated with argentite and copper minerals. They occur in veins, in a quartz gangue. The enclosing rocks are granites or metamorphosed gneisses. These are traversed by diabase in places.

In Pinal, Yavapai and Yuma counties some lead and zinc ores are found, associated with copper and silver deposits. They have been little developed, however, and comparatively insignificant quantities of lead have been produced.

The first locations of the Tombstone deposits were made in 1878, and soon after that lead appears to have been produced along with the other metals. Probably the larger part of the productions given in the table of chapter VI, for Arizona and California together, are to be assigned to Arizona. During the Census year 1889, the following amounts were produced in the respective counties:

Counties.	Tons.	Value.	Counties.	Tons.	Value.
Cochise	1,274	$25,224	Pima	1,152	$48,681
Gila	1	40	Yavapai	105	3,302
Mohave	309	10,445	Yuma	317	11,082
			Total	3,158	918,787

IDAHO.

Idaho is one of the principal lead-producing states in the Union, and the output has been large for the past 10 years. According to

the figures of the Eleventh U. S. Census, the state ranked third, and it still holds about that position.

Idaho has been known as a mining state for over 30 years. Gold was discovered there as early as 1852 [*34, p. 517*], but mining was not begun until about the year 1860. The principal products have, however, been gold and silver, especially the former, of which large quantities have been obtained from placers. Argentiferous lead ores are known to occur in Alturas, Custer, Lemhi, Ada, Owyhee and Shoshone counties. Those of the Wood River district, in Alturas county, and of the Coeur d'Alene district, in Shoshone county, seem to be the most important, and have been by far the largest producers.

Coeur D'Alene Mines.—These are situated in Shoshone county, in the extreme northern part of the State. The country rocks are principally quartzites, but with these are associated shales and schists. They are sharply flexed and trend E.–W. Some of the beds are faulted and deflected, and they are also traversed by eruptives. The ores occur in what appear to be true fissure veins following fault fissures. A mass of breccia generally occurs along the hanging walls, in which ores are found. Most of the lead ores appear to occur near the foot-wall of the fissure, and exist here in thin seams or in large bodies known as bonanzas. The gangue is generally a brecciated quartz with much earthy material [*47, p. 108*].

This is the largest lead-producing district in the United States, since the decline of Leadville's production. The ore is low grade, ranging from 6 to 10 per cent of lead [*195, vol. ii. p. 394*]. Thirteen dressing-works were in operation in 1891. Most of the concentrates are shipped away. The deposits are easily worked, being mostly entered by tunnels in the mountain sides.

The Wood River District.—In this district, are deposits of rich argentiferous galena associated with cerussite and oxides of lead and iron. The deposits are described [*16, p. 2*] [*24, p. 24*] [*83, p. 55*] [*184, p. 249*] as occurring in strata of limestone and quartzite somewhat disturbed by faults. The ore seems to be confined to the limestone, but is of irregular distribution, and does not conform to the dip and strike. Black shales are also found here.

In Owyhee County are the South mountain argentiferous lead ores. The occurrence of these ores seems to be somewhat similar to that of the Wood River district. The country rock is limestone [*161, p.*

194] [*125, p. 55*]. The ore is galena and carbonate of lead, and seems to occur in irregular bodies. Some zinc blende is also found here, and oxides of iron are associated with the carbonates. The ore bodies are faulted in some places. It is reported to be a very rich silver ore. The mines were operated and the ore smelted about the year 1874 [*185, p. 304*], but financial disasters caused cessation of work in 1875 [*186, p 227*]. Since that time little or nothing has been done.

In Boise county, near Pioneerville, several silver-bearing galena veins are reported. Also in Ada county, in what is known as the Heath district. In Lemhi county, the Viola mine has been a large lead producer. In Custer county, lead occurs near Clayton.

History and Statistics.—The discovery of argentiferous galena in Idaho we find noted as far back as 1867, when veins containing this ore are reported in the vicinity of Idaho City [*47, p. 520*]. The South mountain deposits were discovered about 1871, the Wood River district about 1873, the Ada county veins about 1874. The Coeur d'Alene mines are, comparatively, of recent development, having been first discovered in 1884, but are now the largest producers in the state.

The following table, extracted from volume II of the Mineral Industry, shows the production by districts. It is based upon reports of the U. S. Mint, Census and Geological Survey. The productions credited to "Other districts" for the years 1885-88, inclusive, are practically those of the Viola mine in Lemhi county.

THE PRODUCTION OF LEAD IN IDAHO.

	Coeur D'Alene district	Wood River district	Other districts	Total for State
Year.	*Tons.*	*Tons.*	*Tons.*	*Tons.*
1881	....	710	90	800
1882	....	*4,000	100	*4,100
1883	....	6,000	100	6,100
1884	....	7,500	100	7,600
1885	....	6,422	3,578	10,000
1886	1,500	8,232	6,768	16,500
1887	5,980	7,100	6,920	20,000
1888	8,000	5,500	8,000	21,500
1889	18,564	3,970	638	23,172
1890	*19,800	4,500	700	*25,000
1891	33,000	5,000	563	38,563
1892	*27,839	4,500	661	*33,000
1893	*29,563	*2,000	*700	32,263

*Estimated.

MONTANA.

Montana has been, during the past 40 years, one of the great gold and silver producing states of the Union. With these metals, and especially with the silver ores, there are associated various compounds of lead and zinc, along with other base metals. The mining region of the state is principally in the southwestern quarter, in the rugged country of the Rocky mountains. The rocks are granites, limestones and sandstones, traversed by dikes of later eruptive rocks. With these latter, the ores occur. Descriptions of the geology and of the ore deposits of this region are few and very meagre at that. In fact, this part of the country has received comparatively little study by scientific men. Only the briefest description can, hence, be attempted here.

Emmons, in writing of the ores of Montana [*83, p 95*], states that the ores occur in veins in crystalline rocks, or as irregular deposits in sedimentary strata. Many of the former, he states, are of the nature of "metamorphic veins," with no definite wall or limit, at least on one side. These, he considers, have been formed through the replacement of the country rock by minerals in solution. The deposits in limestone are of very irregular form. They sometimes extend across the bedding planes, but are generally coincident with them, or tend to follow the joints and contact surfaces.

The state is at present a large producer of lead. Zinc is, however, not classed among her productions, though it occurs associated with other ores. During early years, lead was not shipped from the state, on account of the heavy cost of transportation and the low price of the metal. The principal lead-ore deposits are in Lewis and Clarke, Beaver Head, Jefferson, Silver Bow and Meagher counties. Smaller quantities are known to occur in Gallatin, Madison, Deer Lodge and Park counties and in the Crow reservation. Zinc blende is associated with most of these, but especially with those of Deer Lodge, Jefferson, Park and Silver Bow counties. Cerussite is also reported to occur in Missoula county, in the St. Regis district [*57.p. 1091*].

In Lewis and Clarke county, the lead ores are chiefly in the southern portion, in and about Helena. Lindgren defines these deposits as true fissure veins, following or adjacent to the contact between granite and a liparitic rock of probable Cretaceous or Tertiary age [*241. p. 422*]. The gangue is principally quartz, carrying argentiferous ga-

lena, with sulphides of zinc, copper, iron and arsenic. The veins vary in width from one to ten feet.

Beaver Head County.—Here are several districts in which silver lead ores are mined; they are in the eastern portion of the county.

In the Bannack district, galena, associated with gold and pyrite in quartz, occurs in a limestone country rock, with a hanging wall of so-called granite. This granite, Emmons thinks [*83, p. 97*], is more properly quartz porphyry or diorite. In the Argenta district, the ore occurs along a similar contact; the formation is the same and the mode of occurrence of the ore is similar. The veins are very abundant here, and more lead was originally found in them than about Bannack. As greater depths were reached in mining, however, the amount of lead diminished.

In the Vipond district, the country rock is a dolomitic limestone. The ore occurs in this in veins and "pockets," from 4 to 15 ft. in width [*182, p. 269*]. The gangue is principally quartz, while the ores are cerussite, galena, blue and green copper carbonates, silver copper glance, horn silver and native silver.

In the Blue Wing district, not far from Bannack, a great number of argentiferous lodes occur, mostly in limestone, though some are in granite. The ores exist in veins or "pockets" from 6 in. to 8 ft. wide. Much zinc blende is associated with the galena in some of these deposits.

At Glendale, in this county, are deposits of argentiferous galena mixed with zinc blende, copper and iron pyrites. These are parallel to the stratification of a bluish limestone. They are mined by the Hecla Consolidated Mining company. The ores contain from 7 to 23 per cent of lead. They are smelted at the works of the company in Glendale. The production of this company during the past thirteen years has averaged over 2000 tons of lead per annum [*195, vol. ii. p. 397*].

In Jefferson County, veins of argentiferous galena occur. They are principally in the northern portion. In the Hot Springs district, about 14 miles south of Helena, is the Legal Tender lode. This has been considered a true fissure vein in granite [*183, p. 230*], and on it was, at one time, the largest and best developed silver property in Montana. The vein was from one to three feet thick. Both argentiferous galena and blende were mined here. Several smaller veins occur in this district, as well as in the Colorado mining district, a few miles farther south.

Silver Bow county, formerly a part of Deer Lodge county, includes the city of Butte and its important mines. In addition, silver-bearing ores are found in what is known as the Flint Creek district, northeast of Butte City. They occur in limestone, and carry zinc, copper and lead minerals. The lodes are said to be near contact with the underlying granite, and to penetrate this rock in places [*182, p. 222*].

The ores of Butte City are all in granite, and are generally parallel to rhyolite dikes which traverse the granite. According to Emmons [*79, p. 54*], two zones of ore deposits may be recognized, the one copper-bearing, the other silver-bearing. In the latter, the ores are silver, lead, zinc and iron sulphides in a siliceous gangue, associated with silicate and carbonate of manganese. In the former are carbonates of copper and other metals, which changed to sulphides with depths. Emmons considers this district as a "fissured zone," the fissuring having been produced by some general dynamic movement which shattered the whole region. The veins are thus not in deep fault fissures, but they were originally narrow crevices along which mineral solutions flowed. By solution and replacement these crevices have been enlarged and subsequently filled with ore. In evidence of this, he adduces the fact that the ore frequently merges into the country rock, and no well-defined or sharp dividing line can be recognized. As opposed to this, however, there is the fact that well-defined walls have been recognized on both sides of a number of these veins. The mineral contents of the vein, Emmons is inclined to believe, were derived from the eruptive rhyolites.

Meagher county.—The Castle district in this county was at one time regarded as of great promise, but recent developments have not been favorable. The ore occurs in chimneys in limestone, or at the contact of limestone with igneous rocks. The ore is lead carbonate and sulphate, with oxide of iron in a gangue of silica [*195, vol. ii, p. 397*].

In the Neihart district, of this same county, are some promising silver-lead deposits. The ore consists of galena in a gangue of quartz and barite, occurring in a fissure four or five feet wide.

In the Crow reservation, at the Clarke Fork mines in the Blackmore and New World districts, large veins are reported to exist, of which the ore carries from 70 to 80% of lead [*185, p. 324*].

History and Production.—Mining in Montana is less than 40 years old. In 1852, gold was first discovered there in placers, but sluice or placer-mining did not begin until 1863. The smelting works of the St.

Louis & Montana Smelting company were erected in Beaver Head county in 1865. The veins of argentiferous galena in Jefferson county were also discovered at an early date and smelting works were erected, but were not successfully operated. In 1866 and 1867, several smelters were erected about Argenta, but, by 1871, these had largely ceased operations, due partly to the fact that the supply of argentiferous lead ore was found to diminish with depth, and, further, because transportation was so costly for this bulky ore. Smelting works were erected at Helena in 1871. In 1873, there were five furnaces in Montana, though only two were in operation. Most of the lead was then held back at the furnaces as litharge, to await cheaper reduction and lower transportation. In 1882, the Hecla Consolidated company of Glendale, in Beaver Head county, was the largest producer. In 1883–84 the same works were prominent; in addition, there was a smelter operating at Clendenning, Meagher county, and also at Maiden and Argenta in Beaver Head county. In 1887, the Helena Mining and Reduction Company at Wicks, in Jefferson county, was a leading producer, and the Hecla Consolidated company was next. During the year 1892, the silver-lead mines in Montana were comparatively inactive [*195, vol. i, p. 305*], and during 1893 the production declined considerably.

Figures of production of Montana lead ore have been very difficult to obtain. The amounts in all the early shipments were included under silver ores, and the lead contents are not known. The following table gives such figures as have been available, and these are chiefly from the various volumes of the Mineral Resources of the United States:

PRODUCTION OF LEAD IN MONTANA.

Years.	*Tons.*
1882 (estimated)	4,100
Of this the Hecla Co. produced 2600 tons.	
1883	5,000
1884	7,000
1885	(?)
The Helena Mining and Reduction Co. produced 3464 tons.	
1889—Beaver Head Co.	3,453
Jefferson Co.	5,081
Meagher Co.	1,060
Other counties	589
Total	10,183

THE DAKOTAS.

The mining region of the Dakotas is in the southwestern part of South Dakota, in and about the Black hills. Here, gold ores have been mined for many years, and this is the region of the much mooted tin ore. The great ore deposits of the Black hills are in Archean rocks, and consist mainly of auriferous pyrite, though lead and zinc also occur.

During recent years, extensive deposits of silver-lead ores have been developed in the vicinity of Galena, in the Bear Butte district, some ten or twelve miles east of Deadwood. Emmons describes these as irregular deposits of argentiferous galena and cerussite, with oxides of iron, carrying gold and silver. They occur in limestone and quartzite, and are both transverse and parallel to the stratification planes [*83, p. 391*].

Mr. F. C. Carpenter considers these contact deposits [*36 p. 582*]. Those at Galena he describes as occurring in Potsdam quartzites and lime shales. They are parallel to the bedding planes, and have, apparently, replaced the lime shales. Intrusive sheets of porphyry occur, also, between the beds of shale.

At Iron Hill, deposits consisting essentially of carbonate of lead passing into galena at depths, are found in Carboniferous limestone. They occupy nearly vertical positions. They are associated here, as at Galena, with porphyry dikes. Mr. Carpenter concludes that these deposits have been formed by aqueous solutions, through metasomatic interchange, as have those at Leadville; also that they were originally deposited as sulphides. He further considers it probable that at least the silver-lead ores were derived from the intrusive porphyry, in which crystals of blende and galena are visible. The gold ore he attributes to a different source.

The development of these lead ores has so far been hardly sufficient for Dakota to be ranked as a lead-producing state. Hence, few figures of production are available. In the Mineral Resources of the U. S. for 1887, we find the Iron Hill Mining Co. of Lawrence county, and the Galena Mining & Smelting Co. of Galena, credited with a joint production of 1000 tons of lead for the year 1887. In Bulletin No. 80 of the Eleventh Census, the production of the state for 1889 is given as 116 tons. In the Mineral Industry for 1892, p. 310, it is noted that small amounts of the ores produced came from South Dakota and Washington.

CHAPTER VI.

INDUSTRY AND STATISTICS OF LEAD AND ZINC.

By James D. Robertson.

THE METALLURGY OF LEAD—THE METALLURGY OF ZINC—THE DISTRIBUTION OF LEAD AND ZINC WORKS—STATISTICS AND PRICES.

Some of the uses to which lead and zinc have been put have already been indicated in a preceding chapter. We shall now treat further of these uses, beginning with a description of the processes by which the metals are obtained from the ores, and of the methods of manufacture into the final products. These metals enter, perhaps, more into our industrial life than do any others, save iron. Lead is most abundantly employed for the manufacture of white lead, but it is also used in the form of pipe, sheet-metal and shot, and, in conjunction with other metals, forms alloys, the most important of which is type metal. It is also of wide application in pharmacy and industrial chemistry.

Zinc, while not used so commonly as lead, is, nevertheless, a very important metal industrially. It is employed in this country mainly to protect iron and steel used in construction, in the form of sheets for various purposes, and in alloys with other metals, forming the brasses and bronzes that are so important for delicate machinery. It is also used in pharmacy and industrial chemistry. In Europe, a large proportion of the zinc made is applied to roofing, a use that has not as yet been adopted in this country.

The metallurgical processes involved in the production of the metals from their ores, and the methods of manufacture by which the metals are changed into such forms as are demanded by the trade, are often so dependent, one on the other, that they will be treated of together.

THE METALLURGY OF LEAD.

Did space and time permit, it would be interesting to describe, in this connection, the early processes whereby the ancients obtained lead from its ores. Such must be omitted, however, and for accounts of these processes the reader is referred to the works of Pliny, Agricola and other early writers. The present article will be confined to an outline of the modern processes of lead smelting.*

While there are quite a number of processes which have for their common aim the production of lead from its ores, the final chemical reactions on which all these processes depend are the same, namely: a preliminary oxidation or roasting of the ore, and a subsequent reduction. The manner in which these reactions are reached varies, and the process selected should depend on the purity and richness of the ore, its quantity, the kind and quality of fuel and the quality of the various fluxes obtainable.

The various processes may be classified, according to the kind of furnaces used, as follows:

1. Log Hearth.	3. Hearth.
2. Reverberatory.	4. Cupola Furnace.

The Log Hearth.—A description of this furnace is introduced here on account of its importance in the early days of lead-smelting in the Mississippi valley. In it all the lead in Missouri was smelted before 1820. It cannot be classed with any other type of furnace, being only an improved form of camp-fire (in which undoubtedly lead ores were originally smelted), surrounded by a wall. The adjoining figure will illustrate its construction. According to Schoolcraft [*203, p. 93*], the furnace was built against the side of a hill, having a slope of about 45 degrees. Three large oak logs were rolled into the furnace, resting on the ledges shown in the figure; small split logs were set up vertically around the furnace, and the ore, in lumps averaging 15 pounds in weight, was piled on top, about 5000

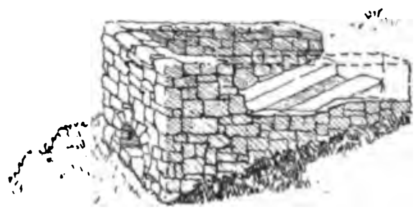


FIG. 1. The Log Furnace.

* In the preparation of this article the writer has consulted many authorities, all of which it is not practicable to mention here. He is, however, especially indebted to Mr. Arthur Thacher, E M , of St. Louis, who made many useful suggestions, and who read the Ms. before it was sent to the printers. Many ideas and some abstracts were taken from Prof. H. O. Hoffman's admirable work on lead-smelting, all of which, it is believed, are credited to the author.

pounds being considered a charge. The whole was then covered with logs and the fire started. This was kept low, the ore being gradually roasted for about twelve hours. Afterward a stronger heat was maintained for another period of twelve hours, during which time the lead flowed out into the basin in front. Sometimes this length of time was not sufficient and another period of twelve hours or more was required, this depending largely upon the skill of the furnace-man. The yield was about 50 per cent of the lead in the ore.

THE REVERBERATORY FURNACE.

The reverberatory is the simplest of all processes. The ore is treated in a furnace of the type which gives the process its name. This furnace is perhaps the least expensive of any now used in lead-smelting. It is of comparatively easy construction, employs wood as fuel and requires no blast in its operation.

The reverberatory process depends on the following reactions:

$$PbS+PbO=3Pb+SO_2$$

$$PbS+PbSO_4=2Pb+2SO_2$$

The ore is first gently heated until a part is oxidized. As a result, some lead oxide and some sulphate are formed, the relative amounts depending upon the temperature at which the roasting is carried on; the higher the temperature, the greater the quantity of sulphate. The bulk of the sulphur being thus eliminated, the temperature is raised still higher, when the oxide and the sulphate react on the remaining sulphide and produce metallic lead, as shown in the above equations. This is an outline of the process; in different places, local conditions have given rise to somewhat varied practices. The more important of these will be described later in some detail, and others will be merely referred to. It may not be out of place to remark here that the reactions in the log furnace are essentially the same as those just described.

The Ash furnace was introduced into Missouri in 1798 by Moses Austin, to supplement the smelting of lead in the log furnace. It was designed to receive the residue or "ashes of lead" from the log furnace, and, as these were already in a more or less oxidized condition, further roasting was omitted and the charge was immediately reduced at a moderately high temperature, in which process the fragments of charred wood in the residue assisted. The general plan of this furnace is shown in the next figure. The slope of the flue was about 5½ ft. in 10 ft. The ashes of lead, or residue, were taken from the

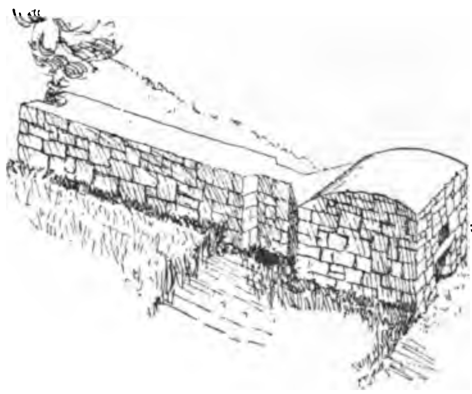


FIG 2. The Ash Furnace.

log furnace, crushed moderately fine, and washed by a rude buddling process. They were then charged into the door at the far end of the furnace, with sand or crushed flint in alternate layers, and, as fast as well heated, were shoved farther in, until a full charge was made. In about two hours, the furnace was ready for tapping. The slag was tapped off first, then the lead, on opposite sides of the furnace. The "ashes of lead" gave about 15 per cent of the lead in the ore by this method. The furnace lasted about fifteen or twenty days, continuous work. It was made of limestone and wore out rapidly.

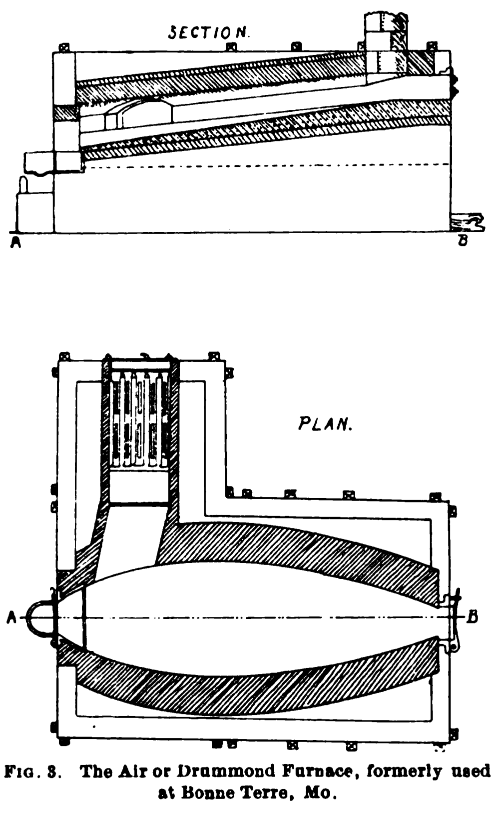


FIG. 3. The Air or Drummond Furnace, formerly used at Bonne Terre, Mo.

The Air or Drummond Furnace.—This furnace was formerly used very largely, and is still used to some extent in the Mississippi valley. It was generally built of stone, although some have been made of red brick and lined with fire-clay. The general design is shown in figure 3. The hearth is usually 9 to 10 feet in length, and 3 to 4 feet in breadth at its widest part, and has a slope of about two inches to the foot toward the lead well. The grate is placed at right angles to the furnace, and is usually about 5 feet in length by 2 feet in breadth. Between it and the furnace, a bridge or low wall of fire-brick is built, over which the flame passes.

The ore, galena, is charged at the upper door, about 1,500 lbs. at a time. It is spread evenly over the hearth, and the temperature is first kept low, during which time partial oxidation takes place. After an hour or two, the heat is raised slightly, though not enough to fuse the ore. Reduction follows and the lead begins to flow into the lead kettle or well. When the flow diminishes, the operation is repeated, the smelter adding some of the ashes from the ash-pit, for the double purpose of making the charge less liable to fuse and of reducing some of the lead by means of the partly charred wood in the ashes. After 10 or 12 hours, the residue remaining in the furnace is all oxidized, and the amount of earthy impurities is so great that very little more lead can be gotten. This residue is then removed and a new charge introduced. The lead in the kettle is skimmed by chips of wood and cast into pigs. The process requires the labor of one smelter and one helper, and consumes about 1½ cords of wood. The yield is generally about 80 to 90 per cent of the lead in the ores.

The Carinthian Furnace.—In Raibl, in Carinthia, the furnace is constructed somewhat differently. The hearth tapers from the middle toward the front or working door, and the fireplace, instead of being at right angles, is parallel to the axis of the hearth, and is very long, about 7 ft., and only 15 inches wide; it is connected with the hearth near the charging door. The ore is thus charged into the hottest part of the furnace, and the lead is worked off in a gradually decreasing temperature, while in the air furnace it works from a cooler into a hotter temperature. The virgin lead obtained by this process is thus produced at a lower temperature, and contains for this reason less impurities than that produced by the air furnace. However, after this portion of the lead, known as the virgin lead, is extracted as described above, a further treatment is given by raising the temperature still higher and working with charcoal breeze until a further portion of lead is extracted. This lead, known as slag lead, contains more of the impurities of the ore, and is usually refined by a process of liquation. Recently, this method has been abandoned at Bleiberg, the Silesian process, described later, being substituted.

Flintshire or English Method.—The main points of difference between this method and the one last described, are that the charge is larger, the furnace is rather differently planned, and is larger also, and a higher temperature is maintained, coal being used as fuel. The

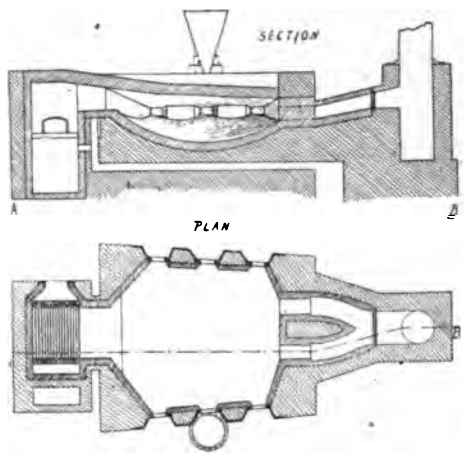


FIG. 4 The Flintshire Furnace formerly used at Frumet, Mo.

general design of the furnace is shown in figure 4. The hearth is trapezoidal in shape, about 10 ft. in length and also in breadth at its widest part. The grate is about 4½ ft. by 2 ft. The furnace is generally built of red brick and lined with fire-brick.

The general outline of the process is as follows: A large charge is introduced and roasted rapidly, with an increasing temperature. Thus, a comparatively small part of lead is obtained. Then, on raising the temperature, metallic lead and sub-sulphide are formed as follows:

$$2PbS+PbSO_4=Pb+Pb_2S+2SO_2.$$

The sub-sulphide thus formed next decomposes, forming lead and the normal sulphide. The charge is then slightly cooled, allowing the sulphide to oxidize, and thus the process proceeds. During this process, an oxy-sulphide of lead, of somewhat uncertain composition (probably PbOS), is also formed; carbon is added in the form of charcoal or fine coal to decompose this, and lime is also added to stiffen the charge and render it less fusible. The lime combines with the residue and the various compounds of lead, forming a slag, known as gray slag.

This method requires very careful work. Four skilled smelters will handle four charges in 24 hours, working 12 hour shifts. About two tons of coal and 300 pounds of lime are consumed. The yield is from 80 to 90 per cent of the lead in the ore. The gray slag amounts to about 25 per cent of the weight of the ore and carries 30 to 40 per cent of lead. The fume, which is condensed in the flues, varies considerably in quantity, and is saved and recharged into the furnace.

In some districts of France and Germany, another modification of this method is used. In all reverberatory processes, the presence of silica in the ore is a serious detriment, as it combines directly with the lead and reduces the product. The French method is designed to treat such siliceous ores. In it the aim is to roast the ore at a low temperature, thus making as much sulphate as possible. The temperature

is then raised nearly to the fusing point, and a large quantity of the oxide is produced, as in the following equation:

$$PbS+3PbSO_4=4PbO+4SO_2.$$

At the same time, carbon is added in the form of fine coal, which reduces the oxide readily to metallic lead, as follows:

$$4PbO+4C=4Pb+4CO.$$

The sulphate which is left over is reduced to sulphide. The reduction of the oxide takes place so quickly that there is no opportunity for the lead and silica to combine. The yield is about 80 per cent of the lead in the ore. The slag produced is greater in quantity, but not so high in lead.

A process, known as the precipitation or Vienne process, was formerly practiced. It consisted in adding scrap iron to the charge in the furnace to desulphurize the galena:

$$Pb\ S+Fe=Pb+Fe\ S.$$

This is now largely abandoned, the use of iron being costly and the fuel expense great; moreover, the sulphide of iron carries off some of the lead with it.

The Silesian Method.—At Tarnowitz, Silesia, an important modification of the reverberatory process is used, that, in some respects, resembles the Flintshire method. The furnace is rectangular, the hearth being about 16 ft. by 9 ft. The fire-place is at the end of the furnace, extending across it, with a grate 8 ft. by 20 ins. The lead is drawn at the end of the furnace farthest from the fire. The ore, which generally contains a small part of the lead, in an oxidized form, is charged through a hopper in the roof of the furnace. About 4 tons, constituting a charge, are spread over the bottom of the furnace and roasted at a low red heat for 3 or 4 hours, during which time the ore is rabbled every 20 minutes, to assist the roasting process. Toward the end, some 300 to 600 lbs. of carbonate ore or flue dust, containing about 45 per cent of lead, are added to increase the amount of oxide in the ore. The fire is then quickened, and soon the lead commences to flow. After this flow ceases, lime is added to thicken the charge, and the process is repeated. This is done several times, the amount of lead obtained at each repetition being less. Before the last reaction takes place, the mixture of dross and coal obtained in poling the lead is thrown into the furnace and worked into the charge and covered with fine coal. The temperature is raised and the last yield of lead made. After this, the residues remaining in the furnace are drawn. The

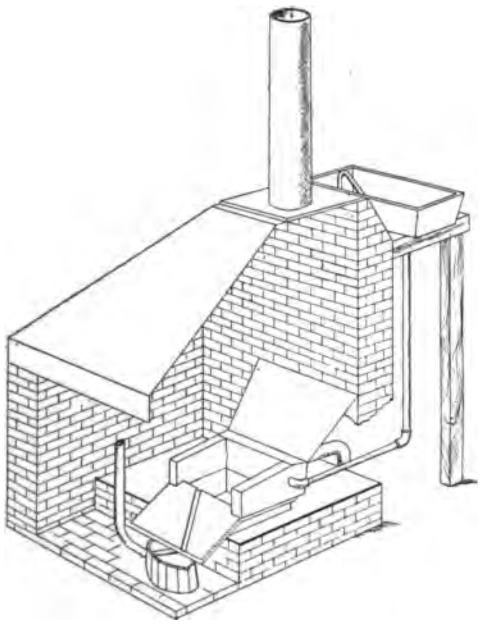


Fig. 5. The American Water Back Scotch Hearth.

will hold about 2,500 lbs of lead. The residues from previous runs are added, with a little charcoal; then, charges of mixed charcoal and crushed galena, about 20 to 30 lbs. at a time. The lead is gradually reduced byoxidation and reduction. A little lime may be added occasionally and the slag scraped off. The lead runs into the well in front of the furnace, and is, from time to time, ladled into moulds. Two men will treat 3000 lbs. of ore in one shift of eight hours. The hearth will yield about 80 to 90 per cent of the lead. It consumes about 14 to 15 bushels of charcoal per shift.

The slags contain upward of 30 per cent of lead, mostly in metallic form, although much is combined. They are treated in a furnace known as a "slag eye," really a low blast furnace about 4 ft. high. This furnace is about 2 ft. wide at the back and 1½ ft. in front; it has one and sometimes two tuyeres in the back. The front is almost entirely closed by a fore-wall that comes down into the sump.

The slag, mixed with sufficient lime and iron (in protoxide form preferably, as the reducing action is not very strong) to make a fluid slag, is charged with charcoal into the furnace. The lead is reduced and collected in the well and the slag allowed to flow out through the hole above in the fore-wall. The slag should not contain over 2 per cent of lead. The lead produced in this furnace is not so pure as that obtained from the hearth. A furnace such as the above will treat 4000 to 5000 lbs. of slag in 24 hours.

The Lewis-Bartlett Process.—In Joplin, Mo., at the works of the Picher White Lead Co., there is a rather peculiar modification of the Scotch hearth. A furnace of large size is used with a heated blast, and a considerable portion of the lead is purposely volatilized for the manufacture of white paint. The furnace is a large, double, open hearth,

THE HEARTH FURNACE.

The hearth process depends substantially upon the same principles as the reverberatory process, save that the roasting and reduction are carried on simultaneously. The furnace consists of a rectangular basin, whose back and side walls are carried up a foot or more, leaving the front and top open. The basin is kept full of molten lead, and on this the ore and fuel are charged. A blast of air plays on the surface, raising the temperature and oxidizing the ore, which is then reduced principally by the heated lead sulphide which has not been oxidized, and also by the carbon. The lead flows off into the well in front of the basin. The different methods in use in hearth practice are due almost entirely to the variations in the form of furnace used.

The original Backwoods Hearth was built entirely of stone. It was awkward and became very hot in working, and thus could be used only intermittently. Further, it was difficult to secure the proper stones and dress them for the lining of the hearth, and the action of the lead oxide on them was quite marked. Later, these stones were replaced by solid cast-iron blocks, called stones by the smelters, which were built into the proper places. While subject to the objection that they were not adapted to continuous work, they were an improvement on the stone. In Rossie, N. Y., a furnace was used for a time which obtained considerable notoriety as the American-Scotch hearth. It consisted of a hollow cast-iron frame in which the blast circulated before being thrown upon the fire, thus producing a heated blast. The heated blast increases volatilization; hence, this furnace was not popular, and, so far as the writer can ascertain, was not used elsewhere except at the Lone Elm works, where the principle of the hot blast is applied for the specific purpose of increasing the volatilization. This will be referred to later.

The Water Back Scotch Hearth.—This furnace, shown in figure 5, is made of cast iron, the basin being cast in one piece, and the back and sides in another piece. There are three tuyere holes in the back, which is made hollow for the circulation of water. This renders it possible to use the furnace continuously, an impossibility in all the earlier forms. The treatment of the ore is so similar in all forms that separate descriptions are unnecessary.

The basin is always kept full of lead. If a furnace is being started, it is filled by melting pig lead. A hearth like that shown in the figure

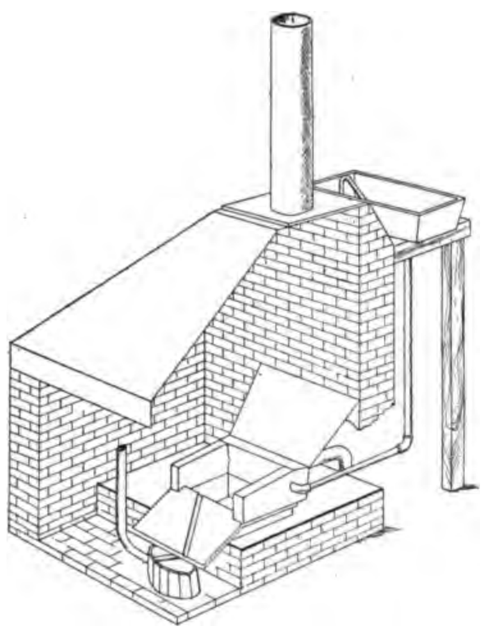


Fig. 5. The American Water Back Scotch Hearth.

will hold about 2,500 lbs of lead. The residues from previous runs are added, with a little charcoal; then, charges of mixed charcoal and crushed galena, about 20 to 30 lbs. at a time. The lead is gradually reduced byoxidation and reduction. A little lime may be added occasionally and the slag scraped off. The lead runs into the well in front of the furnace, and is, from time to time, ladled into moulds. Two men will treat 3000 lbs. of ore in one shift of eight hours. The hearth will yield about 80 to 90 per cent of the lead. It consumes about 14 to 15 bushels of charcoal per shift.

The slags contain upward of 30 per cent of lead, mostly in metallic form, although much is combined. They are treated in a furnace known as a "slag eye," really a low blast furnace about 4 ft. high. This furnace is about 2 ft. wide at the back and 1½ ft. in front; it has one and sometimes two tuyeres in the back. The front is almost entirely closed by a fore-wall that comes down into the sump.

The slag, mixed with sufficient lime and iron (in protoxide form preferably, as the reducing action is not very strong) to make a fluid slag, is charged with charcoal into the furnace. The lead is reduced and collected in the well and the slag allowed to flow out through the hole above in the fore-wall. The slag should not contain over 2 per cent of lead. The lead produced in this furnace is not so pure as that obtained from the hearth. A furnace such as the above will treat 4000 to 5000 lbs. of slag in 24 hours.

The Lewis-Bartlett Process.—In Joplin, Mo., at the works of the Picher White Lead Co., there is a rather peculiar modification of the Scotch hearth. A furnace of large size is used with a heated blast, and a considerable portion of the lead is purposely volatilized for the manufacture of white paint. The furnace is a large, double, open hearth,

built of cast iron and supported on pillars. The sides of the furnace being hollow, the blast flows through them before entering the air-box, thus becoming well heated. The two furnaces are entirely independent. When in operation the hearth is full of molten lead and ore; galena is added together with bituminous coal and a little lime to stiffen the slags. The oxidizing and reducing actions go on simultaneously, but imperfectly, and the ore is only partially reduced. The slag, so called, is worked out by the smelters and taken to the slag furnace.

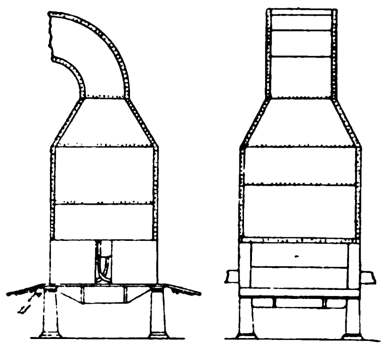


FIG. 6. The Bartlett Scotch Hearth

The products of the first smelting are metallic lead, slag (consisting largely of half smelted ore) and fume, which latter is collected in the fume chambers. This fume is drawn by an exhaust into large bags of unwashed wool that empty into hoppers below. These bags retain all the fume or fine dust, allowing the gases to escape through them. The composition of this dust is shown by analysis No. 11, below.

ANALYSES OF FUME AND SUBLIMED WHITE LEAD PRODUCED BY LEWIS-BARTLETT PROCESS.*

	(1)	(2)	(3)
Pb O	44 18	44.82	25.85
Pb SO_4	43.57	48.76	65.46
Pb S	8.61	....	....
Zn O	0 61	0 27	. 5.95
Fe_2O_3	} 0.07	0.32	0.03
Ca_2O_3		0.05	....
Al O	0.02	0.48	0.02
SiO_2	0.14	0.10	....
SO_2	0.44	1.65	0.04
CO_2	0.08	0.90	1.53
Na_2O	1.31	0.37	1.69
Totals	99.43	99.72	99.65

*The analyses of the various products are taken from an article describing the process by F. P. Dewey [*66*, *p 676*].

The flue dust is next drawn from the hoppers under the bags on to the floor, where it is ignited and burns without the addition of fuel. The composition of the flue dust after burning is given in analysis No. 2. This burnt flue dust, together with the slag before mentioned, is then re-smelted in a slag eye. The slag consists of an agglomerated mass of the various impurities of the ore, fragments of coal, metallic lead, raw and partially roasted galena, together with the lime which was added to stiffen it and make it "ball up" so that it may be readily removed. It will carry about 50 per cent lead and may run as high as 75 per cent. The roasted flue dust and slag are charged into the slag eye with tin-scrap and coke. The furnace is of the cupola type, low and with a stack leading into another dust chamber. The volatilized products and gases are carried into another building, and collected in bags similar to those used in the first operation. The fume is a white impalpable powder, which is packed in barrels and sold as "Sublimed White Lead." Its composition is given in analysis No. 3 of the above table.

The slag from the slag furnace is generally black in color and of a vitreous luster. A portion of it is used in the furnace over and over again, to protect the walls from corrosion. It contains about 10 per cent of metallic lead.

A series of analyses of metallic leads, made by the hearth process, is given in the following table:

ANALYSES OF PIG LEAD PRODUCED BY THE HEARTH FURNACE.

	(1)	(2)	(3)	(4)
Arsenic	0.00019	0.00021	0.00011	0.00925
Antimony	0.00093	0.00266	0.00146	0.00184
Silver	0.00045	0.00025	0.00056	0.00615
Copper	0.00479	0.00463	0.01782	0.03742
Iron	0.00220	0.00777	0.00686	0.02497
Zinc	0.00142	0.02071	0.00033	0.00118
Nickel	0.00047	0.00021	0.00077	....
Cobalt	....	....	0.00005	....
Sulphur	Tr.	....	....	....
Lead (by difference)	99.98850	99.96340	....	99.91919

(1) Granby, Mo., Williams [*238. p. 63*].
(2) Moffett & Sergeant, Lone Elm (Joplin), Williams [*238, p. 64*].
(3) Picher White Lead Co., Joplin, Dewey [*66, p. 687*].
(4) Valle Mines, Jefferson Co., Mo., Williams [*238, p. 67*].

THE CUPOLA FURNACE.

The cupola process introduces few new principles. It differs from the processes just described, in that it divides the operation usually performed in one furnace, into two distinct steps, each performed in a separate furnace. It is adapted to all ores, but especially to the leaner and less pure ones.

In some parts of France and Germany, a process is in vogue by means of which lead ores are smelted in the blast furnace, without a previous oxidizing or roasting, by the use of metallic iron. This process, which has never obtained firm hold in this country, depends on the greater affinity of iron than lead for sulphur. The galena was reduced to the metal by the direct substitution of iron for lead, producing a fusible sulphide of iron, or matte. This process is not, however, a very practical one. The high temperature necessary involves too great a fuel expense, the cost of metallic iron is high and the separation is not perfect. More or less lead is carried away by the matte mechanically, and, when this is roasted and resmelted, it makes an impure lead.

The method in general use in this country is what is known as the Roast-Reduction method. The general outline of the process is to roast the ore in a reverberatory furnace, and, by adding sand, to convert it into the silicate. This is then treated in a cupola furnace and reduced to metallic lead. The various products formed are: 1) metal; 2) slag, consisting of the earthy constituents of the ore, together with the necessary ingredients which are added to flux them; 3) matte, consisting of the sulphur remaining in the roasted ore combined with iron, which is added purposely to liberate it from the lead; 4) speiss, a similar compound formed by arsenical ores, in which arsenic takes the place of sulphur; 5) flue dust, consisting of the volatilized compounds and of those mechanically carried off from the cupola furnace, which is rich in lead and is finally retreated.

Ores consisting of oxidized forms of lead or in which such forms predominate may, of course, be smelted directly, without previous roasting.

Roasting.—The aim of the roasting operation is to oxidize the ore as completely as possible. This is done by exposing it to oxidizing action in a reverberatory furnace, at a gradually increasing temperature. If the ore is not sufficiently siliceous, as is often the case with

Fig. 1.

Fig. 2.

VIEW OF BONNE TERRE FURNACES.

Fig. 1. REVERBERATORY ROASTING FURNACE.

Fig. 2. CUPOLA OR BLAST FURNACE.

the non-argentiferous ores found in limestone regions, a quantity of quartz sand is added. The argentiferous ores usually have a quartz gangue, and seldom, if ever, need any additional silica. This silica serves two main purposes: first, it decomposes the sulphate that may have been formed; and second, it agglomerates the ore so that it may be charged into the cupola furnace without loss. In basic ores, its presence is further necessary to furnish the acid requisite to form the slag. The ore is roasted in a reverberatory furnace on the plan of that shown in figure 7, which represents the furnace used at Mine LaMotte, Mo.; in plate III a photographic view of such a furnace is represented. This furnace has a hearth 55 to 60 ft. in length, and 11 to 13 ft. in breadth. In some cases the hearth is inclined at a slight pitch (1 inch in 5 to 10 ft.), and in other cases it is divided into four or six parts by short steps, the portion between the steps remaining horizontal. The roof is carried on a flat arch about 15 to 20 in. above the hearth. The grate extends across the furnace and is about 10 to 12 ft. long and 18 in. to 2 ft. wide. A bridge of fire-brick, sometimes hollow, to allow of circulation of air, separates the grate from the hearth, and is generally about 20 in. wide and rises 8 to 10 in. above the hearth. When wood is used as fuel, the grate is lowered some distance to allow of a hot fire being maintained.

In some of the more recent furnaces, the portion of the hearth nearest the bridge, where the ore is fused, is contracted so as to concentrate the heat. It is then termed the fusion box. Such a design is shown in fig. 8.*

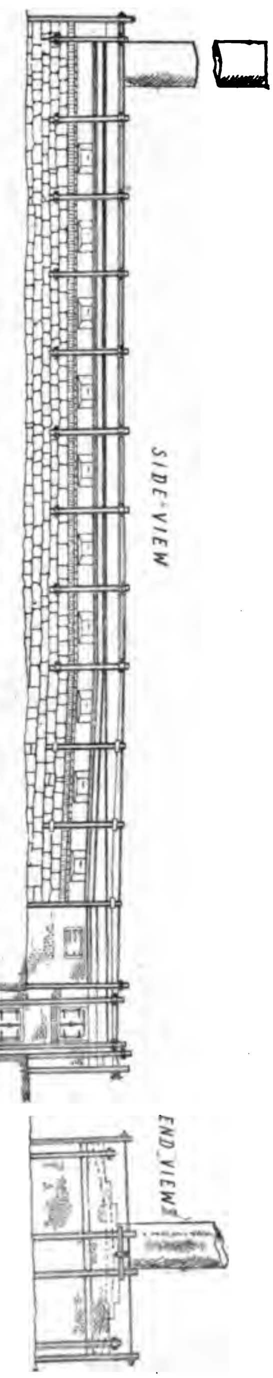


Fig. 7. Reverberatory Roasting Furnace for Lead Ores used at Mine La Motte, Mo.

*It has been stated that this form increases the losses by volatilization, and some of the larger smelting furnaces have returned to the use of the old designs.

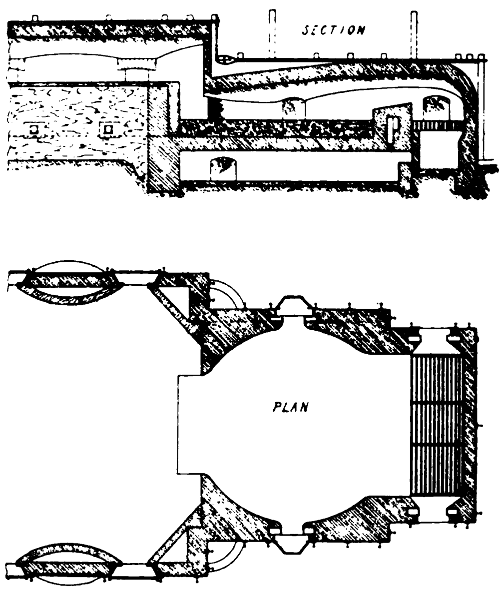


Fig. 8. Fusion Hearth of Reverberatory Furnace used at Omaha and Grant Works, Denver.

The furnace is built of fire-brick, but red brick is often substituted where the heat is not great, as near the flue end of the furnace. The door frames are all of cast iron, and the whole structure is strongly braced by means of buck-staves and tie-rods.

About 1500 to 3000 lbs of ore, crushed to 1-10 inch size and smaller, is charged every six hours, the previous charge having been moved forward. Every hour, and sometimes more frequently, the ore is stirred or rabbled, so as to expose it thoroughly to the oxidizing influence. After it has reached the bridge, during the last two hours, the heat is raised somewhat, and the ore is sintered. If there is need of silica in the ore, it is added at this point. The charge is finally drawn in a pasty condition, cooled and broken up for the blast furnace.

The amount of sulphur remaining in the ore varies. In Europe, with low wages and cheap fuel, it is practicable to reduce the sulphur contents of the roasted ore to one per cent and less (Mechernich, 0.6 per cent); but in this country, 5 per cent is considered fair practice, and it is rare that less than 3 per cent is obtained, and 7½ per cent is not infrequent. This is dependent entirely upon local conditions. In this country, it is found more convenient, on the whole, not to roast so close, and to extract the remaining sulphur in the cupola furnace. One reason for this is, that the large establishments which buy these ores make up a mixture that often contains considerable copper; a certain amount of sulphur is required to combine with this copper to form a matte, and to prevent this metal from going into the slag, where it would be a much harder task to save it.

The fuel used in roasting may be either coal or wood. About ¼ to ⅓ of a ton of bituminous coal, or a half a cord of oak wood is required to the ton of ore, when the process is carried on continuously.

Three men are usually employed continuously on a furnace, in 12-hour shifts. Such a furnace will produce 12,000 lbs. of roasted ore per day of 24 hours; so the average yield is one ton per man per day.

A furnace for roasting lead ores, embodying some rather novel features, has recently been patented by Mr. Richard Pearce, of the Argo works, Colo. It is circular in form, the hearth being a ring about 36 ft. in diameter and 8 ft. in width. Mechanical stirrers, in the shape of long arms, carrying plowshare-like teeth, radiate from a central shaft and revolve slowly, a slot being left in the inner wall of the furnace through which these arms may move. The fire-places, of which there are two, are built on the outside of the furnace. The capacity is reported to be about 22 tons in 24 hours, during which the percentage of sulphur is reduced from 30% to 5 to 7% [*164, p. 513*]. The furnace is an improvement on the old O'Hara mechanical furnace. Another furnace, somewhat similar in design, is the Brown Horse-shoe furnace, which might be used for roasting lead ores. It will be described in connection with the roasting of zinc ores.

Reduction.—The next operation is the reduction of the ore in the cupola or blast furnace. The reactions here involved are as follows: First, the reduction of the lead silicate to metallic lead, by substituting other bases, such as iron and lime, to combine with the silica and form a slag, and the subsequent reduction of the lead oxide by the carbon and carbon monoxide in the furnace. Second, the reduction of the sulphide of lead in the roasted ore by direct substitution of iron for lead, the iron combining with the sulphur and forming a matte.

In connection with the first reactions, the composition of the slags is of first importance. During the last decade, this subject has attracted much attention, and the scientific journals bear witness to much careful thought and investigation.

The slag generally made in lead smelting is a singulo-silicate, or a silicate in which the ratio of the oxygen in the base to that in the acid or silica is as 1 : 1. In some cases, a sesqui-silicate or a bi-silicate may be used, the ratios of which are respectively 2 : 3 and 1 : 2. The bases which may enter the slag are ferrous oxide, manganous oxide, lime, magnesia and baryta. The iron is generally charged in the form of an ore which is easily converted from a ferric to a ferrous condition, or in a ferrous state as iron furnace cinder. Within certain limits, the more iron the slag contains, the greater its fusibility, and so far it is beneficial. Beyond this limit, the tendency is for the iron to be reduced to

the metallic state, forming accretions on the wall which are very disastrous to good work. The function of iron is, as has been intimated, to combine with the silica, setting free the lead and forming a slag. It also combines with the sulphur, setting free lead from the unroasted portions of the ore, and forms a matte. Manganese acts so like iron that it is considered as such in calculating the charge. Lime by itself makes a thick pasty slag, but with other bases, in proper proportions, it makes a very good slag. Magnesia has always been considered as acting similar to lime, but even with other bases its tendency is to make the slag stiffer and less fusible, especially if zinc be present. It is often impracticable, however, to get a limestone that does not contain an appreciable amount of magnesia. Baryta is calculated as lime in slags, but a part of it is liable to go into the matte, thus increasing its density and rendering a clear separation of matte, slag and metal difficult. Alumina is not very frequently found in lead slags. It is introduced with the ore or as an impurity in the fluxes. Its action is to lessen the fluidity, and it probably acts as an acid [*202, p. 58*]. At any rate, more lime and less silica is needed. Zinc, while not rated a slag constituent, is often found in base ores and must be gotten rid of in the slags. It is very objectionable, making thick, pasty slags, and causing a loss in lead and also in silver. Smelters make a higher charge for treating ores carrying over 5 to 7 per cent of zinc. Copper goes into the matte when in an ore, and may be recovered. Arsenic and antimony are volatilized to a certain extent, but enough generally remains to render the lead hard and impure. Arsenic will combine to a large extent with the iron and form a speiss, but the antimony generally goes with the metallic lead.

The commonest slag which is met with in lead smelting is one in which the ratio of FeO to CaO is 2:1, of which the formula is 6 FeO to 3 SiO_2+4 CaO sup 2 SiO_2. The calculated amounts of the constituents are approximately, 40 per cent FeO, 20 per cent CaO and 30 per cent SiO_2. This makes an excellent slag. With ferruginous ores, however, where sufficient lime would make too bulky a charge, a slag with a ratio of 4 to 1 is often used, the formula of which is 6 FeO SiO_2+2 CaO SiO_2, which corresponds to 50 per cent FeO, 12 per cent CaO and 28 per cent SiO_2. Hoffman, from tables compiled from various authorities, says that, in general, lead slags may exhibit the following variations [*108, p. 136*]:

SiO_2, 28 to 36 per cent; FeO, 24 to 52 per cent; CaO, 10 to 30 per cent.

The cupola furnace used is of the general design shown in fig. 9. It may be divided into three parts: 1) the crucible where the lead

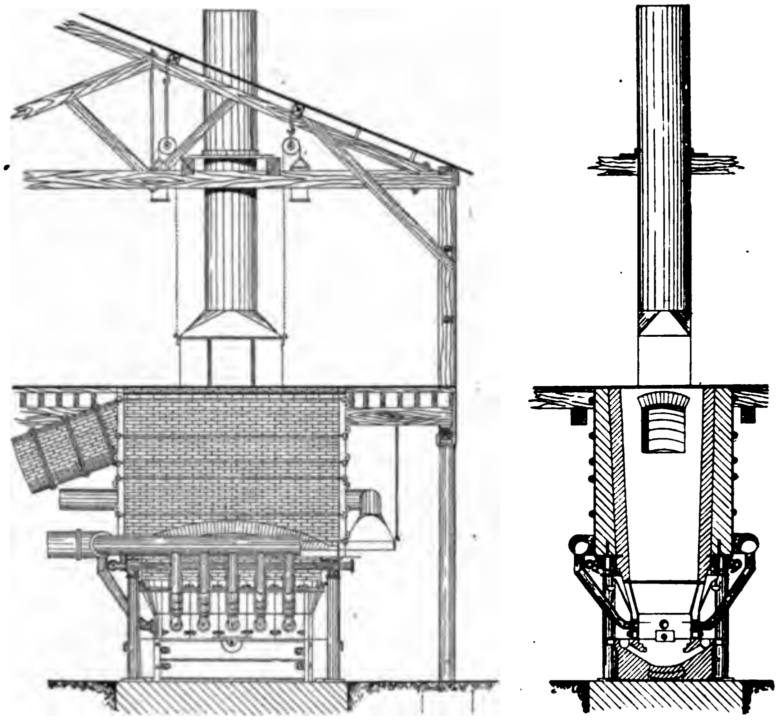


Fig. 9. Cupola Furnace.

matte and slags collect; 2) the bosh, which is the zone of the highest temperature, and is pierced by the tuyeres; and 3) the stack or reservoirs for the ore, fuel and flux. The shape of the horizontal section of the furnace may be either circular (Pilz) or rectangular (Rachette). The latter is, however, becoming much more generally used, because it can be made larger. There is a limit beyond which the blast from the tuyeres will not penetrate the charge, and in a circular furnace this is reached when the diameter is 50 inches. The rectangular furnace is, however, generally built 42 by 120 inches.

The general style of the furnace used in southeastern Missouri is shown in plate III. The foundation should be very solid, on rock if possible. The crucible is built of broken slag, or of clay and coke rammed to the proper shape within a brick wall, with an inverted arch at the bottom. It is surrounded by heavy iron plates bolted together. The walls at the bosh are formed by hollow, cast-iron sections, called water

jackets, through which water flows, keeping the temperature down. Considerable heat is lost here, but as yet no practical plan of preventing this has been devised. With walls built of fire-brick or any other refractory material so far used, the chemical action is so great as to rapidly cut them out. Holes are provided in the water jackets for the insertion of tuyeres, through which the blast is introduced. The stack is built of red brick, quite thick at the base to prevent the loss of heat, and it rests on an iron ring-plate, supported on iron columns. It is lined with fire-brick in such a way that it may be relined without disturbing the outer wall. According to Hoffman [*195, vol. ii., p. 433*], the Zeehan and Dundas furnaces in Tasmania, and the Broken Hill furnaces in New South Wales, are using wrought-iron water jackets to form a portion of the stack above the tuyeres. This was tried at the LaPlata furnaces in Leadville several years ago without success, there being an excessive heat loss. The furnace is from 10 to 16 ft. in height from the tuyere to the charging door. The chimney above the charging door is variously made. In silver-lead works, where there are frequently several furnaces operated in the same building and the fume is of value owing to its silver contents, the fume and furnace gases are taken off just below the charging floor through a pipe, the gases from all the furnaces leading into one chamber. In such works, a stack above the charging floor is often omitted, a plate being laid across the hole through which the charge is thrown into the furnace. In non-argentiferous lead furnaces, the stack is generally carried up some 10 ft. above the charging door, which then is in the side of the furnace.

The lead is usually tapped from a basin, connected with the crucible, known as a siphon tap. The slag and matte are tapped from the same orifice in the front of the furnace, sometimes reinforced by a water-jacketed lining, such as the Arents or Luerman cinder tap. Recently, trials have been made toward using separate openings for taking off the matte and slag.

The charge of ore, fuel and flux is calculated by the metallurgist from the analyses of the various ingredients. The amount of fuel present, called the fuel ratio, should be about 15 per cent, but it frequently runs below this. The lead contents should be about 15 per cent also, but with pure ores this percentage is frequently decreased to 10 per cent, and sometimes less.

The charge determined, the ore and flux are mixed and brought to the charging door and evenly distributed in the furnace. The fuel

is added separately where needed. At the slag-tap, the furnace man draws off the slag as it forms, also the matte, removing the latter for retreatment. The matte is in general reroasted on heaps or kilns, or possibly reverberatories, and charged again as iron flux. If it contain copper, this metal may be thus concentrated, after which the matte is sent to the refining works for the extraction of the copper.

The blast is furnished by a blowing engine, either Baker or Root, and is usually of about 8 ounces pressure. A heavier blast would cause too rapid working, and the separation would not be perfect.

The capacity of a furnace varies a great deal with the character of its work. In southeastern Missouri, a 48-inch circular furnace will put through a charge of about 40 or 50 tons in 24 hours, producing about 18 tons of lead.

The labor necessary to run such a furnace depends, to a certain extent, upon the natural advantages of its location. A charger and two wheelers are needed on the charging floor, and a boss and two roustabouts on the furnace floor. To these must be added the proper number for coke, ore and flux hauling to the furnace, and for carrying away the slag and matte and pig lead from the furnace. In a large plant, such as the Omaha and Grant works in Denver, where there are nine cupola furnaces all working on the same ore mixtures, the labor per furnace can be reduced to a smaller number than is possible where only one or two furnaces are in use.

After the lead has been tapped from this furnace, it is refined. The purer leads of the Mississippi valley are simply submitted to a melting at low heat and poling, either by stirring with green wood or by means of a jet of steam passed through the kettle of molten lead.

COMPARISON OF THE THREE METHODS OF LEAD SMELTING.

The three processes of smelting lead ores, the reverberatory, hearth and cupola, have each their defects and their advantages. The early methods, such as practiced with the log and ash furnace, are not adapted even to the pioneer work of today; the labor and expense that they entail would hardly allow of their use, even under the most primitive conditions.

The reverberatory and hearth methods require very pure ores. With ores carrying over 5 per cent of silica, it is impossible to use them economically. On pure ores, these methods give very fair results when care is taken in the smelting. The yield amounts to 80 or 90

per cent of the lead in the ore. The hearth requires rather purer ores than the reverberatory, and the capacity is nearly three times as great. It also has the advantage of being readily started and stopped without much expense. The yield of this furnace is sometimes given as about 80 to 90 per cent of the lead in the ore. That the furnace will yield a large percentage with careful working is readily admitted, and with pure ores, the amount of slag, though rich, is very small; but there is a loss through the slag and also by volatilization that probably amounts, with best practice, to at least 10 per cent, and more often to 15 or 20 per cent.

The cupola furnace is adapted to ores that are less rich, and also those that contain impurities which would cause severe losses if treated by any other process. Also, when there is a large amount of ore to be treated, the cupola process is more economical. Despite its complexity, proportionally fewer skilled laborers are required, the various stages of the process allowing of a division of the labor whereby a smaller number of skilled men is required per ton of metal than in any other process. Further, less fuel per ton of product is required. A better quality of fuel is necessary, however, and, in some localities, the extra expense on this account would be an offset to the other advantages. The losses in the cupola process are set at about 8 per cent by western silver-lead smelters in buying ores. They ought not be greater than 10 per cent with careful management.

DESILVERIZATION OF BASE BULLION.

The lead produced in smelting argentiferous ores is designated base bullion. The furnace is generally run so as to produce a base bullion, carrying about 150 ounces of silver and up to 10 ounces of gold per ton. It was formerly the custom to cupel all of the lead produced: that is, to melt it on a hearth with a blast playing on the surface in such a way as to oxidize the lead, and thus obtain the silver and gold which would not oxidize. The losses and expense of this treatment were so great that it has been abandoned, except in very rare cases.

The Pattinson Process.—In 1833, the Pattinson process was introduced. This depended upon the fact that an alloy of lead and silver melts at a lower temperature than does pure lead. The lead-silver alloy was first purified by melting in a softening furnace, the impurities which rose to the surface being skimmed off. It was then transferred

in a molten condition to the central one of a row of kettles, the temperature being kept low so that a partial solidification ensued. This lead which first solidified was removed from the central kettle, and as it still contained some silver, it was transferred to another kettle on the right. The remaining alloy, being correspondingly enriched, was transferred to the kettle on the left. This procedure was continued until one end of the row was reached by the completely desilverized lead, and the other end by the rich lead-silver alloy. The enrichment possible in this process is not very great, and the amount of the alloy to be cupelled large.

The market or refined lead carried from ½ or 1½ ounces of silver to the ton, and the rich lead ran as high as 500 ounces.. This process is no longer practiced in this country, and in Europe it is not in such general use as it once was.* A modification introduced by Luce and Rozan, who stirred by steam, and drew the liquid lead off, leaving the crystals of the poorer alloy in the kettle, is described by Hoffman [*108, p. 301*].

The Parkes Process.—This is based on the fact that silver and gold form, with zinc, an alloy of less density and less fusibility than lead. Thus, on the introduction of 1 to 2 per cent of zinc, the precious metals form a hard crust which floats on the surface of molten lead. This alloy contains more or less lead, and, also, any copper that may be in the base bullion; for this reason it is necessary to purify the lead beforehand to a greater extent than is required in the Pattinson process. To effect the purification, the base bullion is first melted down in a furnace of the reverberatory type, which is in reality a liquation furnace. A low temperature is maintained, and the lead is frequently poled. Air is freely supplied, and the impurities that gather on the surface are skimmed off. About 33 to 35 tons of lead are melted down, and from this, 30 tons of purified bullion goes to the desilverizing kettle. This kettle is hemispherical in shape, 3 to 3½ ft. in diameter, and made of cast iron. The lead is kept liquid in the kettle by a low fire. If it contain gold, a small amount of zinc, varying from 50 to 200 lbs. per ton of lead, is added, according to the amount of gold. This is called the "dore" zinc, and the crusts that rise contain most of the gold. After this, the silver zinc or the "big zinc" is added in amounts of from 400 to 600 lbs. per ton of base bullion. The crusts then formed are taken off, more zinc is added in smaller amounts, and the crusts removed, successively, until the lead is completely desilverized. This generally

*For fuller detail see Percy [*179, p. 121*]; and note by Ellis Clark, Jr. [*180, p. 458*].

takes four or five additions of zinc. The crusts are then distilled in a retort, the zinc being caught and condensed in a receiver, and the rich silver-lead alloy that remains is ready for cupellation.

A modification of this process, by Roessler and Edelman, has been in use in Belgium for some years. This differs from the older method in using zinc containing 0.5 per cent of aluminum in place of the pure metal. The effect of this addition is the complete desilverization of the base bullion with one addition of zinc. The resultant silver-bearing alloy is treated either by dissolving it in hydrochloric acid or in dilute sulphuric acid, thus obtaining the silver as a slimy residue, the zinc going into solution. Or, it is treated by electrolysis, which gives a very satisfactory separation. This process is described more fully in the Mineral Industry for 1893, p. 442, from which the brief remarks given above are taken.

Cupellation.—This rich bullion is now introduced into a cupellation furnace and the lead oxidized, the silver and gold remaining in the metallic state. There are two methods of conducting the cupellation.

In the German process, a large fixed hearth is used, the roof being movable. The hearth or "test" is 12 ft. square, and is composed of marl or limey clay, well tamped. The metal is charged in quantities of about 25 tons. It is melted and the impurities skimmed off of the top, after which the cupellation process goes on at a lower temperature, the oxide of lead or litharge flowing off into a pot arranged to catch it. For about 15 hours the oxidation products are impure, from the amount of antimony, tin, copper and other foreign metals which remained in the lead and have been concentrated here. After this, the litharge flowing off is pure enough to be placed on the market, and much of the German litharge is made in this way. Toward the end, the litharge becomes so rich in silver as to necessitate its being saved for retreatment. After about 80 hours from the beginning of the process, the silver brightens or "blicks." It then contains about 94 per cent of silver and is removed, and its refining completed on another hearth where a blast is used.

The other process of cupellation, the English, uses a smaller furnace, and a hearth or test that is movable and quicker of operation. The furnace is of the reverberatory type, but the test is of elliptical shape, about 3 ft. in length and 2 ft. in width. It is a cast-iron frame with flat pieces across the bottom, something like a gridiron. It is

filled with marl or a mixture of limestone and clay, tamped to a depth of about 6 ins. It rests on a platform on wheels, which is pushed into place in the furnace, so that a test may be removed and a new one inserted at any time. In some of the later designs, a water-jacketed litharge top is added to prevent the corrosion of the filling. After the lead is melted, the dross and litharge flow off into a pot. A slight blast is used. The bullion is generally carried to about 50 to 70 per cent, when it is ladled out and finished in another furnace, a new charge being added at once to the first. The silver is refined in the second furnace to about 997 or higher, the limits being 995 and $999\frac{3}{4}$. According to Hoffman, 1000 lbs. of 70 per cent bullion can be cupelled in about 5 hours by the labor of one man and the consumption of 1500 lbs. of nut coal. The losses are about 5 per cent. The English method is now adopted in this country almost exclusively. While it makes richer litharge, this is due in part to the fact that the bullion used is generally so rich as to render the production of rich litharge a necessity. The ease with which the operation may be conducted, the longer life of the test, as well as the saving in labor and fuel, makes it the more economical of the two processes.

THE MANUFACTURE AND USES OF LEAD PRODUCTS.

The uses to which lead is put are so numerous, that a full description of them cannot be attempted here. We shall, therefore, consider only the more important, and give a short description of the methods of manufacture.

By far the most important use of lead is in white lead. Nearly one-half of the metal consumed in this country annually is transformed into this pigment. Lead is also extensively used in the manufacture of pipe for water supply and other purposes. The fact that lead is extremely ductile and will allow of considerable expansion on the freezing of water in such pipes, without rupture, renders the metal very useful for these purposes In the form of sheet lead, it is used for linings when necessary to exclude moisture, and for the linings of sulphuric acid chambers. For all ordinary forms of shot for sporting purposes it is extensively used, although for military purposes iron and steel are being introduced. Lead forms a series of interesting and important alloys, among which may be mentioned type metal, babbit metal, white metal, organ pipe composition, and the fusible alloys used in electric lighting. It enters into the manufacture of flint glass, cut

glass, cathedral glass and artificial gems. Lead is the basis of several other pigments besides white lead, notably, chrome yellow, Turner's yellow, red lead, orange chrome. In pharmacy, the acetate, carbonate, iodide, nitrate and oxide are used, and in various applications in industrial chemistry its compounds are of much importance.

White Lead.—White lead is generally understood to mean a compound of lead carbonate and hydroxide, containing two parts of the carbonate to one part of the hydroxide. As the term is used in this country, it also implies the manufacture by such a process that the product is absolutely amorphous and not crystalline.

White lead was known to the Romans, and was manufactured by them essentially in the same way that it is made today—the Dutch process. Indeed, it is believed that the process was introduced into Holland from Italy, where, during the Middle ages, its manufacture had been carried on quite extensively. The process, which has held its own so successfully to the present day, consists in exposing the lead to the vapors of acetic acid and carbon oxide. The lead, having a great affinity for oxygen, is quickly attacked and a film of oxide forms. Part of this is changed, by the action of the acetic acid vapors, into both the normal and the basic acetate of lead. The latter salt is changed to carbonate by the carbon dioxide present; while the normal acetate, combining with the oxide, forms a basic acetate, which is in time changed to carbonate, as above. These reactions continue so long as there is any lead remaining, the action becoming slower as the compounds formed cover the surface of the lead to a greater depth [*177, p. 204*].

The operation is actually conducted as follows: The lead, which is generally desilverized and refined lead, is cast into thin sheets, either rectangular or circular, about 8 inches in diameter. These sheets have numerous holes of about one inch in diameter, to allow free passage of the gases. From six to ten of these sheets are placed in and over earthenware pots, not unlike flower-pots in shape, save that they have a small chamber at the base for holding the acetic acid. This acid, diluted, is poured in and the pots set closely together in a bed of spent tan-bark. The bed is about 40 ft. by 20 ft. in superficial area, and after a layer of pots is placed, it is packed loosely with the tan-bark. A loose floor of planks is next laid over these pots, and this is followed by another layer of pots and tan-bark, and so on until a heap about 20 ft. high has been made. A chimney of plank of

five flues, each about 6 ins. in diameter, is erected in the center of each half of the bed, to control the temperature, and the lead is left to corrode. The tan-bark, decomposing, furnishes the heat and the carbon dioxide. The temperature rises to 180° F. in the bed, and the corrosion is allowed to go on for about three months. After this the bed is opened and the sheets are taken to the separator, where the white lead and the uncorroded metallic lead are parted. A corrosion of 90 per cent is considered very good work, although the average will be nearer 75 to 80 per cent. After separating, the white lead is ground with water between blue stones, and then floated, to divide the finer grades from the coarser. It is then drained, dried in open pans by exhaust steam, and finally ground in oil.

Many different processes and modifications of processes have been devised, with the idea of shortening the time necessary to complete the manufacture of this substance. The direct production of carbonic acid, the use of other sources of heat, the dissolving of litharge in acetic acid and the subsequent passage of carbon dioxide through the solution, may be mentioned as some of the main features of these devices. The product thus obtained is not, generally speaking, equal in opacity and covering power to that produced by the Dutch process. Where the time consumed is short, there is a great tendency in the product to become crystalline, and consequently less opaque. White lead of commerce is frequently adulterated with barite or heavy spar, white clay, zinc oxide and chalk.

The Picher Lead Co., of Joplin, Mo., manufacture a sublimed white lead, as described on page 207. This differs in composition from the product of the Dutch process, but is used for similar purposes.

Litharge.—The monoxide of lead, PbO, is usually produced by submitting molten metallic lead to a gentle oxidizing action in a reverberatory furnace. In Germany, a considerable quantity is obtained from the cupellation of rich, lead-silver bullion. It is used in the manufacture of glass to some extent, although the red oxide has been substituted somewhat in later years.

Red Lead.—This substance is a compound of the monoxide and the dioxide of lead, and has the formula 2 PbO, PbO2. The coarser grades are made by gently heating litharge in a reverberatory furnace into which but a limited amount of air is allowed to enter. For making the finer grades, which are used as artistic pigments, white lead is used in place of litharge, and is oxidized gently in a furnace or revolving retort.

Chrome yellow and orange chrome are compounds of lead and chromium. The former, neutral lead chromate, is made by adding to a solution of lead acetate a solution of potassium di-chromate, when a copious precipitate of lead chromate is thrown down. It is also made by digesting artificially prepared lead sulphate in a warm solution of neutral potassium chromate. The orange-chrome is a basic lead chromate, and is made by boiling the normal chromate with caustic potash, the result being that one-half of the chromic acid is abstracted from the lead chromates. Mixtures of these two compounds give various shades of orange. The lead chromate is frequently mixed with lead sulphate, barite or gypsum, to give lighter tints of yellow.

Pipe.—Lead has been used in the form of pipe for water supply and for sanitary purposes for many centuries. The old Roman baths, at Plombiers, in France, show the remains of lead pipe used to convey the waters for bathing purposes. Piping was formerly made entirely by casting, but for many years the method known as "squirting" has taken the place of casting. The molten metal is poured into an iron cylinder, which has in one end a piston, working by hydraulic pressure. In the other end is a hole, whose diameter is the external size of the pipe to be made, and within this is a die, whose diameter is the internal diameter of the pipe. The lead is kept at a temperature just above the point of solidification, and the pressure of the hydraulic piston forces the pipe out of the annular space in finished shape.

Sheet Lead.—Owing to its ductility and impermeability to moisture, lead is frequently used in the form of thin sheets for lining various receptacles. It is made from sheets cast into convenient sizes and from 3 to 6 inches thick. These are passed under heavy rolls until the required dimensions are reached.

Shot.—This article of manufacture is one of considerable importance in this country, although in Europe, iron and steel have replaced it to a noteworthy extent for military purposes. Shot is made by dropping molten lead from a considerable height through a sieve into a vessel of water. A small amount of arsenic, about one per cent, is added to the lead to give it fluidity, and to cause it to take a spherical shape when dropped. It also makes it harder when cold. The shot is rolled down an inclined plane to separate the imperfectly formed individuals, and is then sized by passing through screens. It is next polished by revolving in cylinders with plumbago, and is then ready for the market.

Alloys.—A considerable quantity of lead is made every year, known as antimonial lead. This comes from the drosses obtained in refining bullion, and contains from 15 to 20 per cent of antimony. The greater part of this is used in the manufacture of anti-friction metal and type. Nearly 6000 tons of antimonial lead were produced in the United States in 1892. This requires a considerable addition of pure lead to make the proper composition for type metal, which is composed of 34 parts of lead and one part of antimony. The presence of antimony makes the alloy expand at the moment of solidification, thus giving a clean cut casting. It also makes the type harder and more durable. Such an alloy is so hard as to bear considerable pressure without great wear, and still is not so hard as to cut the paper. It fuses at a low temperature and does not oxidize readily.

Babbit metal and the other cheaper anti-friction alloys are composed of lead and antimony in varying proportions. They furnish a material which is cheap and answers the purposes reasonably well. Organ-pipe metal is composed of equal parts of zinc and lead. An alloy of 80 parts tin and 20 parts lead is used for ornamental castings.

Lead has been used frequently in alloys for cooking utensils. This is dangerous, unless great precautions are taken. A small amount of antimony present in the lead renders it very susceptible to oxidation in the presence of water. An alloy of tin and lead containing 16 to 18 per cent of the latter is, according to Thurston, not sensibly attacked by vinegar or the acids of fruits, but with a larger proportion, the results are liable to be injurious.

THE METALLURGY OF ZINC.

The methods of extracting metallic zinc from its ores are in a very backward state, when compared with those of lead and other useful metals. Much labor and thought have been expended in the hope of discovering a new process for the direct and continuous production of zinc, but so far without success.

History.—Zinc was not known to the ancients in its metallic form. They knew the carbonate—calamine as it was formerly called—and were accustomed to reduce it in crucibles, with copper and charcoal, to produce brass. This method of making brass was in use well into the Nineteenth century. The first works for the industrial production of zinc were established in Bristol, by John Champion, in 1740. In 1798, the principles on which is based the modern Silesian zinc process, were discovered in that country, and the industry started, slowly at first, but more rapidly after the beginning of the present century, when knowledge of the details of the English methods of manufacture was brought to Upper Silesia [*195, vol. ii, p. 636*]. In the meantime, Abbe Dony, in Belgium, accidentally discovered the method of distilling metal from the ore. His discovery was, apparently, entirely independant of that made in Silesia some years before. He endeavored to put his ideas into practice, but failed for want of financial support. After the death of Dony, Dominique Mosselman took up the work and devoted himself to the manufacture of the metal, and to increasing the demand and finding a market for it. This was the beginning of the great Belgium zinc industry. Thus, the Silesian zinc industry, and that of Belgium, were begun within a few years of each other, and gradually grew to the extensive and important operations of the present day. Mr. W. R. Ingalls [*195, vol. ii, p. 632*] notes that the development of the Silesian zinc industry, early in the Nineteenth century, was due to the introduction of a knowledge of the English method of smelting, and calls attention to the singularity of the fact that this knowledge should have been brought to Silesia, on the border of Poland, while in Belgium, separated from England only by a narrow strip of water, no trace of a knowledge of these methods obtained. The two processes, thus originating nearly side by side, continued to develop along different lines, until quite recently, when various modifications were gradually introduced, which drew them nearer together.

Chemistry of the Processes.—The ores of zinc that can be successfully treated for the production of the metal are: the sulphide or blende, the carbonate or smithsonite, and the hydrous and anhydrous silicates, calamine and willemite. The oxide, zincite, might be used, but it is generally found associated with iron, and is too impure; it is used mainly for the manufacture of zinc white.

All processes for the extraction of the metals from the ores involve the converting of these ores first into the oxide, with the exception of the silicates, calamine and willemite. These ores are simply calcined to drive off the water which may be present, in chemical combination in the case of calamine, and mechanically entrained in the case of willemite. The carbonates, smithsonite and hydrozincite, are also calcined to drive off the carbon dioxide and water.

The sulphide or blende (sphalerite) requires a more prolonged treatment. It is heated in a finely divided state, in an oxidizing atmosphere, until the sulphur is driven off and the zinc is oxidized.

During the process, the temperature gradually increases as the charge is moved toward the fire, until, near the end of the process, the ore is at a bright red heat. It is then necessary to further raise the temperature, that any zinc sulphate formed in the cooler parts of the furnace may be broken up and the zinc remain, so far as possible, as the simple oxide. At the same time, the temperature must not be raised too rapidly, or there will be an excessive loss of zinc by volatilization. The ore having been converted into oxide, it is now ready for reduction to the metal.

Zinc oxide and silicate, in the presence of carbon or carbon monoxide, are reduced to metallic form only at an incipient white heat (about 1300° C). At this temperature the zinc is in the form of a vapor, which does not become liquid until the heat is lowered to incipient redness (1200° C); therefore, the only means of obtaining the metal is by the process of distillation. The ore, crushed fine and mixed with the proper amount of carbon, is heated in a clay retort to an incipient white heat. From this, the zinc vapor passes into a conical clay condenser, whence, in a liquid state, it is tapped off and poured into moulds.

The process outlined above is followed essentially by all producers of zinc at the present day.

Mr. W. R. Ingalls, in the Mineral Industry for 1893, p. 657, says:

"It is uncertain whether the reduction of zinc is effected by carbon or carbon monoxide. The preponderance of evidence, however, seems to be in favor of the former. It has been shown that nearly pure carbon monoxide escapes from the

condensers, which can be explained if the carbon forms only carbon monoxide ($ZnO+C=Zn+CO$), or if it forms carbon dioxide ($2ZnO+C=2Zn+CO_2$), which is subsequently reduced again ($CO_2+O=2CO$). The latter process requires 73,000 heat units, while the former only takes 56,000, and is therefore more probable.* A series of experiments to determine this were made at the Wilhelminehutte (Upper Silesia), with very instructive results. In these, the ore to be reduced and the reducing agent were charged into a muffle in different layers, separated by pieces of lime. The zinc oxide and carbon were not therefore in contact. The yield of zinc obtained from these muffiles was so small that all could be attributed to the reducing action of carburetted hydrogen in the carbonaceous material.

"Concerning these experiments, Herr Bergrath Bernhardi, director of the Wilhelminehutte, wrote as follows:

"On the other hand, the remaining possibility that it is chiefly the solid carbon which reduces the zinc oxide is itself a great riddle. Some bodies can act chemically one on an other only by direct contact, and it is inconceivable that the zinc-reduction process can be carried out in the muffle in this manner so completely as it is really done. We cannot imagine how every atom of zinc oxide in a piece of zinc ore can come in contact with an atom of solid carbon. Whether the active molecular movement of the glowing fragments of ore and carbon play a part in this, or whether at the temperature prevailing in the muffle there is formed a lower oxide of carbon (a compound of carbon and carbon monoxide), must remain undetermined. It has been proved by many experiments, and the results of actual practice, that as intimate mixture of ore and carbon as possible is desirable; if the ore is too coarse, or the charge is not well mixed, the yield of zinc falls off. The ore and reducing material must not be too fine, however, else the charge in the muffle will be too dense, and the gases developed will not have the necessary freedom of escape."

The losses incident to the process may be summarized as follows:

1. *Losses during Roasting.*—The main loss in roasting appears to be mechanical. This may be effected directly by dusting, and also by the reduction of some of the zinc sulphide to metal in the condition of vapor, which is immediately oxidized into a flocculent powder and lost. It is possible that some portion of the zinc sulphide is volatilized unchanged (see Percy, Metall. of Zinc, and Sabatier, Encyclop. Chemique Art. Zinc.), but this is denied by many zinc smelters in this country. The losses in roasting have been placed at about 3 per cent by some managers of works, although in a direct experiment made by the writer some seven years ago on weighed charges of raw and roasted ore, the actual loss in zinc contents was between 9 and 10 per cent.

2. *Incomplete Roasting of the Ore.*—In general, this means the formation of sulphate of zinc toward the end of the process. The sulphate is readily reduced to sulphide in the retorts, in the presence

*Wagner's Chemical Technology, New York, 1892, p. 214.

of incandescent carbon; but, as zinc sulphide is unchanged by heating with carbon, it is evident that each molecule of sulphur will hold back a molecule of zinc from reduction. Now, as zinc sulphide is composed of 67 per cent zinc and 33 per cent sulphur, each pound of sulphur left in the roasted ore means the loss of two pounds of zinc in the residue. Thus, one per cent of sulphur in the roasted ore will cause a loss of 100 pounds of zinc in one smelting furnace charge of 5000 lbs. Sulphur in the coal in the retorts operates, of course, in the same way.

3. *Oxidation of Zinc Vapors.*—The oxide of zinc is reduced by contact with carbon, or carbon monoxide, at a high temperature, zinc, carbon monoxide and some carbon dioxide being formed. This latter compound, while usually very stable, is reduced by zinc, both liquid and vapor, when below the temperature at which zinc oxide is reduced by carbon monoxide. Thus, when the zinc vapor is formed and passes into the condensers, any carbon dioxide present will oxidize part of the zinc. Zinc in this vaporous state is also very partial to the oxygen of the air, as may be seen by the burning of the vapors at the mouths of the condensers, in zinc works. A portion of the zinc vapor, which cools rapidly in the condensers, is deposited as finely-divided metal; other portions brought into contact with carbon dioxide give rise to the formation of the carbonate. Thus, a considerable quantity of finely-divided zinc, carbonate and oxide is formed, which must be retreated.

4. *Other Minor Sources of Loss.*—More or less of the zinc oxide escapes reduction from the formation of fusible compounds in the retort, due to the impurities of the coal, the gangue of the ore, etc. The silicate of zinc is not thoroughly reduced by the means employed. The retorts also, when new, absorb a considerable quantity of zinc, amounting to as much as 20 per cent in some works.

The losses from various sources other than that of volatilization in roasting amounts to about 10 per cent. Ingalls states that the total loss in distillation varies from 10 to 25 per cent, and that in Belgium and Rhenish Prussia a loss of 10 per cent represents the best average work. Thus, the total losses are rarely under 20 per cent, and more frequently 25 to 30 per cent.

THE ENGLISH PROCESS.

This process was in practice in Bristol, England, during the latter half of the last century, and continued until after the middle of this century. It consisted of a furnace, in which are placed large clay cru-

cibles, filled with a mixture of powdered ore and coal. A tube leading through the bottom of the crucibles carried the zinc vapors as fast as distilled into a condenser below. This process is quite slow, and the yield is small, unless the time be unduly prolonged. The consumption of coal is high, being about 20 tons of coal to one ton of metal produced. Only calamine and smithsonite were used in this furnace, hence only preliminary calcining was necessary in preparing the ore. The process has not been used for many years. Dr. Percy speaks of having seen it in operation as late as 1859.

THE BELGIAN PROCESS.

The Belgian process was first successfully put into operation by Mossellman in 1818. Since that time, improvements have been made in details of the process, but no change in the principles. The *rationale* of the process has already been outlined in the description of the chemistry. As this method is one very largely in use in Europe, and the one exclusively practiced in this country for the manufacture of metallic zinc, we shall consider it somewhat in detail.

Preparation of the ores.—The calamine and smithsonite are calcined in furnaces very similar to lime-kilns; when drawn, the ores are crushed by a jaw crusher and rolls, and screened to about $\frac{1}{20}$ of an inch.

The blende, after having been dried, is also crushed and screened to approximately the same size—more care, however, being taken to secure a finely divided product, because of the roasting to follow.

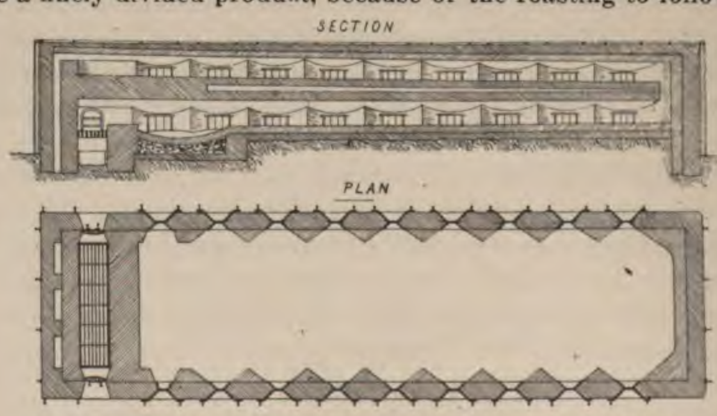


Fig. 10. Two-Hearth Reverberatory Roasting Furnace for Zinc Ores.

Roasting.—In this country, the prevailing practice a few years ago was to roast the ore in long reverberatory furnaces, of two hearths,

one above the other. A furnace of this character, shown in figure 10, was about 65 ft. in length and 12 ft. in width, having about 1000 ft. of hearth area. The ore was introduced at the end farthest from the fire, in charges of about 5000 lbs., and moved toward the fire-place, emerging in from 12 to 32 hours. More recently, in some establishments, furnaces have been erected with from three to seven hearths, one built over the other, and correspondingly shorter. In these furnaces, the amount of coal used is variable, but is very nearly equal in weight to the ore. In one plant, where the roasting was done in both styles of furnace, the two-high hearth furnace roasted 5000 lbs. of ore in 24 hours with 5200 lbs. of coal, and the four-high hearth furnace roasted 6200 lbs. with the same amount of coal. In Europe, the laws require the fumes from the roasting furnace to be so treated that they will not be harmful nor objectionable in odor when they emerge. This has stimulated the utilizing of the vapors for the manufacture of sulphurous and sulphuric acids, and for many years no furnaces have been built there which have not had this idea in view. The distinguishing feature of these furnaces is the provision of separate flues for the gases from the fire and for the fumes from the ore, so that the latter are not unnecessarily diluted. Several patterns of furnaces are in use today. The principal are the Hasenclever, the Eichorn-Leibig, and the new Hasenclever. A short description of these is given in the Mineral Industry for 1893 [*195, vol. ii, p. 647*], and other references are quoted there.

In this country, only one company, Matthiessen and Hegeler, of LaSalle, has designed its furnaces with a view to utilizing the sulphur vapors. This company uses furnaces with seven hearths, which are heated by gas, furnished by ordinary gas producers. The gas travels through flues alternating with the ore hearths. The air, which is admitted to furnish oxygen, is first heated. The ore is moved from hearth to hearth by mechanical rakes, somewhat on the principle of the Spence furnace. In operation the furnace is said to be entirely satisfactory.

The Collinsville Zinc company, of Collinsville, Ill., and the Glendale Zinc company, of St. Louis, have recently introduced a mechanical furnace for roasting blende, which is apparently very successful, although it is not intended to save the sulphurous gases. This is known as the Brown Horse-shoe furnace, and consists of a hearth built in the shape of a segment of a circle. The outside diameter is

about 55 ft.; the ore hearth has a width of 8 ft. and a superficial area of about 1200 sq. ft. The ore is fed into the furnace at one end, through an automatic hopper, which feeds a fixed amount whenever the mechanical stirrer, called a buggy, passes beneath it and disengages the valve closing the hopper. This buggy is a long frame of channel iron stretching across the furnace; it is provided with teeth which rake the ore, and which consist of rectangular plates of mild steel; wheels at each end rest on tracks that run around the whole furnace; the wheels are furnished with ball-bearings to reduce the friction; the driving apparatus is simply a wire cable, running around the furnace on the inside in a gutter of vitrified brick. The buggy has a grip similar to that of a cable car, which is thrown in and out of gear automatically. There are four buggies, two of which rest in the space not covered, and are cooled by the blast from a small fan, while the other two are raking the ore. It takes two minutes for one buggy to make the trip. The heat is furnished by four fire boxes provided with step grates. These are distributed around the periphery of the circular hearth. The furnace is reported to roast 12 to 15 tons of blende in 24 hours. The roasting is uniform, and the product carries less than one per cent of sulphur. It requires the work of two men, and three tons of coal are consumed in that time.

The losses by volatilization vary with the furnace and the care used in operating. They are liable to reach 10 to 15 per cent. The Brown furnace is said to cause less loss by volatilization than the old style furnace.

The sulphur contents of the ore after roasting should be about 1.5 per cent. Careful work may reduce this, and with careless work the percentage may reach a much larger figure.

Reduction.—The form of furnace used for reduction of the oxide of metallic zinc varies considerably, depending somewhat on the method of firing. In furnaces fired by producer gas, the rows of retorts are generally longer, and only three or four high, while in directly fired furnaces, such as the majority of those in this country, the rows are shorter and seven or eight high. The number of retorts is quite variable, being 93 in some of the older furnaces, to 128 in later forms of the direct-firing furnaces. It is customary now to build two furnaces, back to back, with but one wall between them, to economize both in first cost and management. Figure 11 is one of the later forms of direct-firing furnaces.

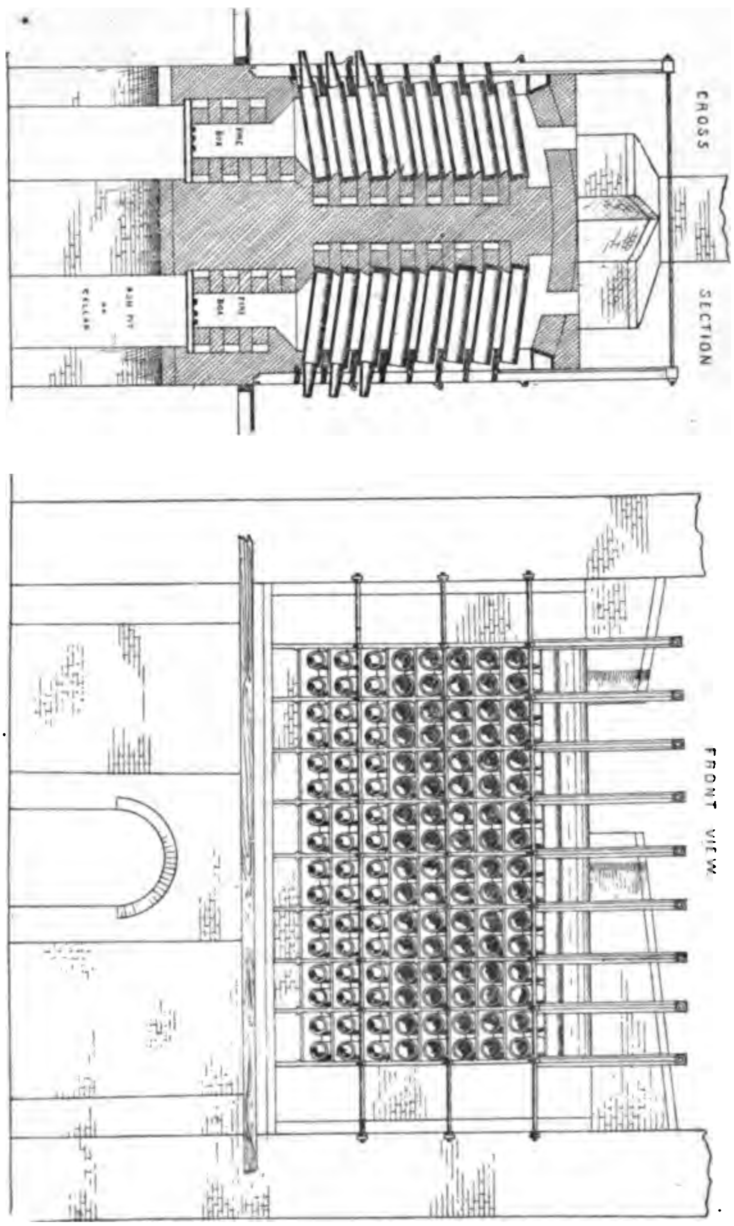


FIG. 11. The Belgian Zinc Furnace, used at Collinsville, Ill.

The fire-place is 22 feet in length and 18 inches in width. The bed of coals is 5 feet deep, the object being to produce a heavy flow of gas, and thus to carry the heat to the upper retorts. The retorts rest on shelves built on the back wall, and on the iron frame-work which forms the front of the furnace. Two retorts occupy each of the square holes, and are luted in place with fire-clay. The retorts have a forward inclination of about 3 inches in their length of 4 feet. The condensers are luted in place, and are usually supported at the end by a fragment of brick.

The furnaces in this country are seldom fired by producer gas, the managers claiming that they can do cheaper work by direct firing with the cheap slack furnished by the mines. At points, however, where better grades of coal have to be crushed for direct firing, the expense is greater, and producer firing is more economical. Regenerative systems are used considerably in Silesia, but in the Belgium works they are being gradually abandoned in favor of the direct producer firing, as the hydrocarbons from the coal, as well as the fine vapors from broken retorts, condense in the checker-works and cause serious trouble.

The roasted ore is charged to the furnace mixed with about 40 per cent of its weight of crushed coal, or of a mixture of coal and coke. The coal should be carefully selected with a view to low sulphur and ash. The mixture is then charged by means of small shovels into the retorts. The amount charged will vary, of course, with the size of the retort, but, with the ordinary retort used in this country (4 ft. long and 8 ins. internal diameter), a furnace with 112 retorts will take about 4600 pounds of ore, and one with 128 retorts usually takes about 5300 to 5500 pounds. Allowance must be made for the charging of the blue powder, which will be referred to later, and which occupies nearly one-fourth of the retorts. The ore is charged once in 24 hours—the fire being allowed to die down first before charging, in order that the reduction may not proceed too rapidly at first. When the retorts are filled, the condensers are luted on. These condensers are conical vessels made of fire-clay, about 12 ins. long and 6 ins. in diameter at the larger, and 2 ins. at the smaller extremity. In the lower rows, where the heat is greatest, sheet-iron extensions of the condensers, called "prolongs," are added, so as to insure the condensation of the zinc. These "prolongs" are 15 ins. long and fit over the condenser, and are closed at the other end. The metal is tapped three times in 24 hours. After

the last tapping, which occurs at about 6 o'clock in the morning, the retorts are cleaned and prepared for a new charge. The amount of fuel used varies somewhat, but about 6 to 8 tons per furnace of 112 retorts in 24 hours is a fair average.

The losses incident to the reduction process have been mentioned before. Those which arise from impurities of the ore and coal are variable, and usually can be partially controlled by proper roasting and selection, and careful choice of charging coal. The main losses, and those not so easily remedied, are due to the reoxidation of the zinc after the reduction from oxide. Some of the zinc may be seen burning at the mouths of the condensers. Considerable zinc is converted into blue powder. This consists mainly of finely-divided metallic zinc, each particle of which is coated with a film of oxide. It is formed, in all probability, by the sudden condensation of the zinc vapors at a temperature much lower than is necessary for their condensation. The blue powder, of which the production amounts to about 5 or 10 per cent of the metal made, cannot be melted down and poured, owing to the oxidation which takes place so readily in this fine state of subdivision. It is, however, readily reduced to metal in the retorts at a lower temperature than is generally necessary for the ore. It is consequently recharged into the upper row of retorts with a little ore, and redistilled. This, of course, reduces the capacity of the furnace, but it should be recollected that above the fifth row of retorts the heat is not sufficient to reduce ordinary ores, and an easily-reducible mixture must be charged.

Miscellaneous.—All zinc works are obliged to manufacture their retorts and condensers, and, incidentally, the special shapes used by them.

The retorts are made of a good quality of fire-clay, tempered with about one-third its weight of "chamotte," which is fragments of the old retorts pulverized. The clay and chamotte are crushed to $\frac{1}{20}$ of an inch and less, and mixed in a pug mill with the proper amount of water. Retorts were formerly made by hand, but now are generally made by machine, somewhat on the principle of a sewer-pipe machine, which is quite uniform and rapid in its work. After the retorts are made, they require drying in a heated room for some months before use, so that it is customary to keep a large supply on hand drying. When needed, they are selected from the stock and put in a small firing furnace of the bee-hive type, and burned for 12 hours, at the end of

which time they are taken out and put in the smelting furnace at a white heat. The condensers are made by hand moulds at odd times. They are composed of one-third fire-clay and two-thirds chamotte, and less care is needed in their manufacture. About 2 retorts and 10 condensers are used daily to each 100 retort furnaces; but, of course, the consumption varies according to the skill of the workmen.

A slightly modified form of the Belgian furnace, known as the Welsh furnace, has been introduced in the Morriston works at Swansea, Wales. The furnace, as described [*229*], is built like a Belgian furnace of the old type. There are six tiers of retorts, 14 in each tier. These retorts have a section that is egg-shaped, for the sake of strength, and the two lowest rows have an air channel, illustrated in figure 12, that allows a high temperature without breaking. This permits the smelting of ores carrying 10 per cent of silica and 22 per cent of iron, as well as of calamine carrying 23 per cent of lead, without any important increase in breakage. The fire-places are lateral, five in number, each 2 ft. by 0.55 ft. It is stated that the loss in zinc is 17.5 per cent, against 21.08 per cent in a Belgian furnace using the same ores. The advantages claimed are, a more uniform heating, less labor, more complete reduction and a longer duration of plant. Such retorts as these have not been used in this country, though oval-shaped retorts of other patterns are.

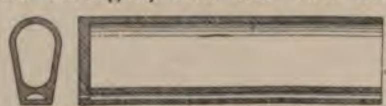


FIG. 12. Oval Retort used in Welsh Furnace.

THE SILESIAN PROCESS.

This process is similar in many respects to the Belgian. The ores are prepared in the same manner by calcining or roasting. The reduction furnace is different, however. It is nearly square, and is built of fire-brick, with a grate in the center, which is fed through a fire-door at one end of the furnace. Above this, is a fire-brick floor, open over the grate, upon which the muffles are arranged in rows on each side of the furnace. The muffles are 4½ to 5 ft. in length, 6 inches wide and 18 to 20 inches high. Unlike the Belgian retorts, they are supported along the entire base, which is made as narrow as possible, thus giving the maximum exposure of surface to the flame. This method of supporting the muffle allows a high heat to be used without sagging, and consequently a higher yield of zinc is obtained than by the Belgian process. This furnace is used only for the treatment of poor ores,

such as the silicate or carbonate of the Silesian provinces, where ores with 18 or 20 per cent of zinc are treated with profit. In consumption of fuel and labor, this process is rather more expensive than the Belgian. A combination of the Silesian and Belgian types is sometimes seen, in which there are two and sometimes three tiers of muffles.

The greatest improvement of late years is the adoption of a new type of condenser for these furnaces. Mr. Ingalls describes the different forms at some length in the Mineral Industry [*195, vol. ii, p. 661*]. In these, the muffles set well inside of the furnace, and are provided with condensers of different patterns, which effect an almost complete condensation of the zinc vapors.

IMPROVEMENTS AND BY-PRODUCTS.

Improvements.—The present methods of treating the ores are, as has been stated before, extremely crude and expensive. So far as the roasting is concerned, the introduction of mechanical furnaces and the utilization of the sulphur vapors promise to lessen the expense. The process of reduction, however, continues to present great obstacles to improvement. First, it is not a continuous process; each successive charging of the ore necessitates lowering of fires and cleaning of retorts, thus causing a large consumption of fuel and labor. Further, nearly 25 per cent of the metal in the ore is lost in the various parts of the operation. A quantity of finely divided metal, mixed with the oxide, is made at each operation. This cannot be melted, but must be redistilled, thus cutting down the capacities of the furnaces three-fourths. Much of the metal burns at the condenser mouth, and a large quantity is left in the retorts unreduced, and is thrown out when the retorts are cleaned. Added to these objections is the further one that, in the furnaces now used, ores containing any considerable admixture of foreign metallic sulphide or oxide cannot be treated. Many ores are found, especially in the western parts of this country, which are composed principally of blende, with an admixture of iron and copper pyrite and some silver. These ores are too poor to smelt with lead for their silver contents, and some means is desired for treating them, so as to save the zinc and silver and, if possible, the copper.

Many experiments have been made in the treatment of zinc ores in the blast furnaces, but none have so far given much promise of success. The difficulty has nearly always been in keeping the zinc reduced.

Mr. Chas. Kirchoff gives briefly, but forcibly, the following facts which must be borne in mind [*133, p. 451*]:

"Zinc melts at 412° C., and it volatilizes at 1200° C ; but zinc vapors, according to F. Thum, are formed already when the heat reaches 520° C. Zinc oxide is reduced, as well by solid carbon as by carbon monoxide, at a minimum temperature of about 1300° C.: that is, above the point of evaporization, facts which necessitate distillation. Below this temperature the reduction of oxide of zinc by carbonic oxide ceases." .... "The greatest difficulty to be encountered, however, is the facility with which zinc, when once in the gaseous state, is reoxidized by carbonic acid or water. Carbonic acid attacks zinc from the temperature of its melting point—the violence of the action increasing with the temperature. As we have seen, oxide of zinc is reduced at a temporature of about 1300° C.—metallic zinc and carbonic acid being formed. The gases, in order to be free from carbonic acid, must, therefore, either be passed through a column charge of some thickness, which is not hot enough to generate zinc, or it must pass through a layer of carbon at a heat above the temperature of volatilization of zinc. If these precautions are not taken, the carbonic acid, formed by the reduction of the oxide of zinc, will cause the formation of a deposit of oxide of zinc as soon as the temperature of the gases sinks low enough to prevent the immediate reduction of any oxide of zinc which may have been formed."

It is thus seen that the condensation of the zinc vapors is the one great difficulty to overcome. So far, no scheme has been brought forward which will eliminate carbon dioxide and air from the condensers, and, while these are present, we cannot expect to obtain a high yield of the metals free from oxide. The passage of the metallic vapors through incandescent carbon has been tried, but so far has not proven a success. Some late experiments on the direct reduction of zinc are noticed in recent issues of Berg- and Huettenmannische Zeitung (Oct. 13 and 20, 1893).

Acid Manufacture.—In many European plants, the gases derived from the roasting of the blende are utilized for the manufacture of sulphurous and sulphuric acids. The process of manufacture of the former in Upper Silesia was invented by Messrs. Hanisch and Schrœder, and is described by Karl Eilers [*75*] substantially as follows: The blende roasted in muffles gives off its gases, composed mainly of sulphur dioxide, at a temperature of about 400° C. These gases are cooled to nearly a normal temperature, and pass into a tower filled with broken coke or checker work, over which water trickles. Here, the sulphur dioxide is removed almost entirely, and the unobjectionable gases pass off. The solution of sulphurous acid thus retained is then heated to 100° C., and agitated to remove the sulphur dioxide. The gas is then

collected and reduced by compression to liquid form, and put in vessels for transportation and sale.

Sulphuric acid is made at numerous places in a similar manner to that employed when pyrites is the source of the sulphur. The gases from the roasting ore are passed into Glover towers and oxidized, and the solution is concentrated by evaporation to oil of vitriol, or purified by distillation in platinum-lined retorts. Only one establishment in this country manufactures sulphuric acid, namely, the Matthiessen and Hegeler Zinc Company of LaSalle, Ill.

THE MANUFACTURE AND USES OF ZINC PRODUCTS.

The uses to which zinc is put are based upon its slight alteration in the air, and second, upon the possibilities of rolling it into thin sheets. These uses are manifold. Prof. W. H. Seamon has recently enumerated the uses of this metal so fully that his words are reproduced here, with some additional notes [*85, p. 169*]:

"Zinc is largely converted into sheet-metal, particularly in Europe, in which form it is principally employed for roofing purposes, for sheathing vessels, taking the place of copper and yellow metal. In thick plates it is used for the preservation of boilers. For this purpose a plate of rolled zinc is suspended by an iron rod in the boiler; the galvanic current set up not only prevents incrustation, but saves the wear of the boiler at the expense of the zinc. About 180 pounds per annum is consumed for every 100 H. P. It is also suspended in the feed water-heater to clear the water, with satisfactory results.

"Zinc nails are employed for the purposes of fastening the sheet-metal to sheathing, and for holding the slates of roofs in place.

"Rolled zinc can be chased, spun, punched or stamped into useful and ornamental forms of great artistic beauty, and is employed for the construction of ornamental ceilings, mouldings and friezes. Rain-water cisterns, downfalls, water-cans, bath-tubs, wash-boards, soap-dishes, stair treads, coal-scuttles and other articles of utilitarian character in household economy are made from the metal. The metal toys made abroad are usually composed of sheet zinc. It is also used in making the hard foundations for cloth and linen buttons. Sheet zinc and zinc foil are used in lining packing cases and wrapping goods to preserve them from dampness or water. Sheet zinc, specially prepared, is used in the art of zincography, which is so much cheaper and more rapid than that of lithography. In glazing paper large sheets of heavy zinc are used. Perforated sheet zinc is used for blinds, flower baskets, meat-safes, screens, etc. Zinc is quite ductile, and is drawn into wire from 0.019" inch in diameter and upward. In this form it is used for clothes-lines, hair-pins, netting and in tying up vines. In the form of rods, plates, cylinders, etc., zinc is largely employed in electrical batteries. It may be drawn or compressed into any desired form.

"Zinc is well adapted for castings; it takes a very sharp impression of the mold, and it is quite fusible; it is largely employed in the manufacture of statu-

ettes and other objects of oramentation. They are highly polished, and frequently colored to resemble other metals. So beautiful are they that many of their possessors would find it difficult to believe that the beautiful ornaments of their handsome parlors were made from common zinc.

"Zinc has long been employed in Europe for monumental purposes, and has there stood the test of time and exposure. In the United States it is now being introduced for such purposes under the name of 'white bronze.' It is usually finished off with a sand-blast, which gives the metal a beautiful rough finish, far more beautiful than granite or marble. A number of the best monuments erected in this country in recent years have been made from this material. It is cheaper than granite or marble, and is more susceptible of artistic treatment. It is far more durable in this climate than stone of any quality. Its beautiful dull gray color harmonizes with the surroundings of and is appropriate to a cemetery. The metal becomes, if anything, more beautiful with age.

"Burial cases are not only lined with sheet zinc, but sometimes the entire body is made of it. It preserves the body, and should always be employed in those instances where the remains must be transported for long distances previous to interment."

The use of sheet zinc for roofing purposes has been carried on for a number of years in Europe. The Vieille Montagne Zinc company, which produced about 58,000 tons of sheet zinc in 1893, sold about three-quarters of this production for the manufacture of zinc roofing. It is stated that as a roofing material it is superior to slate, tiles, sheet lead and all forms of iron. It is of very light weight, compared with other materials; 100 square feet of No. 4 gauge (0.032 in. thick) weighs about 125 pounds, thus allowing the use of lighter purlins in the construction of the roof. On exposure to the air it becomes covered with a thin coating of oxide, which gives it a very pleasing gray color, and which renders painting unnecessary. Unlike galvanized and other forms of sheet-iron, it is not affected by the weather, other than in becoming coated with the slight coat of oxide referred to. In Europe it is fashioned in various forms, either plain or rolled in artistic designs of tiles, which are of attractive appearance. Zinc roofs in Europe are said to have lasted as long as 50 years with only nominal repairs. In this country, no use has been made of zinc for the covering of structures, but doubtless in the near future this important branch of the zinc industry will receive due attention.

In addition, zinc is used to a large extent in the manufacture of brass and of various composition metals. The increased use of delicate machinery of late years has given an impetus to this brass industry. It is used also in the manufacture of galvanized iron and barbed wire, of which an enormous quantity is consumed in the United States.

A notable quantity is used in the desilverization of base bullion. This metal also enters into various pharmaceutical preparations, in the form of acetate, bromide, carbonate, chloride, iodide, oleate, oxide, phosphate, sulphate and valerianate. The oxide, or zinc white, is extensively used as a paint for certain purposes, and the chromate is also used by artists as a yellow pigment.

Consumption in the United States.—There were, during 1892, 84,082 tons of zinc manufactured in the United States, 6247 tons exported and 205 tons imported; hence, the net amount of zinc used in this country was 78,040 tons. The following table, compiled mainly from information furnished by Prof. W. H. Seamon, gives an approximate estimate of the way in which this zinc was used:

TABLE GIVING APPROXIMATE ESTIMATE OF CONSUMPTION OF SPELTER IN THE U. S. IN 1892.

	Tons.
Galvanizing sheet-iron and barbed wire	35,000
Brass manufacture	20,500
Sheet metal	15,500
Desilverization of bullion	3,500
Monuments, etc	300
Miscellaneous and unaccounted for	3,240
Total	78,040

Sheet Zinc.—Sheet zinc is manufactured today by only two firms in the United States—the Mattheissen & Hegeler Zinc Co. of LaSalle, Ill., and the Illinois Zinc Co. of Peru, Ill. Zinc for rolling should be nearly free from iron, as this metal makes the zinc brittle and rotten. If lead is present also, the effect of the iron is increased, but small quantities of lead alone (less than 1½ per cent) do not injure the product. Zinc is rolled at a temperature of about 120° C. At this temperature it is quite ductile, while at temperatures much above or below this point it is rather brittle. The plates of spelter are first roughed down or rolled between heavy rolls, and trimmed to the desired weight. They are then finished by passing through lighter rolls. Between these two operations, and also in the last stage, they are annealed in boxes in a furnace. After being rolled to the thickness desired, they are trimmed and packed.

Galvanizing.—It was early noticed that a thin covering of zinc over iron plates retarded the oxidization of the iron, and made it much more durable. The zinc coating was originally applied to iron by galvanic action, from which comes the name. For many years, however, it has been the custom to immerse sheet-iron in a bath of molten metal. The bath of molten zinc is covered with a layer of ammonium chloride, to prevent oxidation. By this process, wire used for various purposes is also coated—barbed wire being, perhaps, the most important.

Alloys.—The principal alloys of zinc are the brasses, or the compounds of zinc and copper. These vary considerably in composition, according to the purpose for which the alloy is wanted. Brass, generally speaking, is not very strong. It is weaker than either of its components. While the tensile strength of copper is about 24.6 tons per square inch, and that of zinc 15.2 tons per square inch, an alloy of 10 parts copper and 1 part zinc has a tensile strength of 12.1 tons, and an alloy of 1 part copper and 4 parts zinc has a tensile strength of only 1.8 tons per square inch [*222*]. It follows, therefore, that while brass is suited to the smaller parts of machinery, it should not be used for such purposes as tie rods, chains, or any parts which are subjected to great tensile strain. Brass, for delicate parts of machinery, contains usually 20 parts of copper and 29 parts zinc. This alloy has a high coefficient of expansion (0.000,055 per centigrade degree), and fuses at 1021° C. Castings made of it shrink about $\frac{3}{16}$ in. per foot in cooling.

Muntz metal, a sheathing for ships, is composed of from 50 parts copper and 50 parts zinc to 67 parts copper and 33 parts zinc.

German silver is an alloy of 60 parts copper, 20 parts zinc and 20 parts nickel. It is used extensively for mathematical and scientific instruments. It is easily worked, moderately hard, and does not oxidize. Chinese *tutenag*, or white copper, is composed of copper 44 parts, zinc 40 parts and nickel 16 parts.

Zinc oxide.—Zinc oxide in this country is made entirely from carbonate, silicate and oxide ores, and not from the metal, consequently no mention is made of this product in the estimate of the consumption of metal given on p. 241. When the ores of zinc, excepting the silicates, are roasted, they are changed to oxide. With the oxide there is retained all of the impurities of the ore, iron, silica, lime, etc., and the color is a dingy yellow. For the purpose of paint, it is necessary to produce a purer article.

In Europe, this is accomplished at a comparatively high cost, by submitting metallic zinc to oxidizing influences. This produces a superior quality of oxide, of which a considerable quantity is imported into America, where it commands a high price on account of its purity.

In this country, however, zinc white is made by processes based on the patent issued to Samuel Wetherill in 1855. The ore, previously roasted, is mixed with coal and heated on a bed of coals at a sufficiently high temperature to reduce the zinc to metal, which, being in the form of vapor, is quickly reoxidized by the carbon dioxide, and drawn off through a pipe into a chamber, where it is collected in muslin bags. The carbonate, silicate, and oxide ores are preferred for this treatment. When blende is used, the small percentage of sulphur remaining gives rise to zinc sulphate. This process was used at Hopewell, Washington county, Missouri, charcoal being used for fuel; but the product was defective in color [*239, p. 426*].

THE DISTRIBUTION OF LEAD AND ZINC WORKS.

From the descriptions already given, it is seen that while there are a number of processes by which the ores of lead may be reduced, there is but one process in general use in this country by which zinc ores are treated, namely, the Belgian; and, were it not for the extremely low price of fuel and labor in Europe, the same would probably hold there.

The distribution of lead and zinc works is affected by natural conditions, such as the nature and supply of ore and fuel, and by cultural conditions, such as facilities of transportation, access to markets, etc. Differences in processes cause the furnaces producing these metals to group themselves in different ways. The various processes of lead smelting are each adapted to special conditions; the simpler ones are in general best suited to pure and rich ores, and small outputs; while the cupola process is economical in its application, but practically stands alone as regards treatment of lean and poor ores and mixtures, and for large outputs. Thus it is that the reverberatory and hearth processes are rarely used in this country, except in the Mississippi valley, where there are a large number of small deposits yielding very rich and pure ores, which are mined at a low cost and smelted at intervals. The cupola furnaces, on the contrary, requiring large and constant supplies, and smelting almost any conceivable mixture, are located, not necessarily at any one mine, but so as to be readily accessible to many sources of supply of both ore and fuel.

LEAD-SMELTING WORKS.

In the United States.—In this country there are a number of lead smelters, mainly of the cupola type. Those of the reverberatory and hearth types are confined to the Mississippi valley, and their production is trifling, with the exception of the Picher plant, elsewhere described.

The principal smelting works in this country, as furnished by Dr. M. W. Iles, Superintendent of the Globe Smelting and Refining company, are as follows:

Omaha & Grant Smelting company, Omaha, Nebraska and Denver, Colorado.
Globe Smelting & Refining company, Denver, Colorado.
Philadelphia Smelting & Refining company, Pueblo, Colorado.
Colorado Smelting company, Pueblo, Colorado.
Pueblo Smelting & Refining company, Pueblo, Colorado.

Consolidated Kansas City Smelting & Refining company, Argentine, Kansas, El Paso, Texas, and Leadville, Colorado.

Balbach Smelting & Refining company, Newark, New Jersey.

Germania Lead works, Salt Lake City, Utah.

Hanauer Lead works, Salt Lake City, Utah.

Pennsylvania Lead company, Mansfield, Pennsylvania, and Sandy, Utah.

Selby Lead works, San Francisco, California.

St. Louis Smelting & Refining works, St. Louis, Missouri.

St. Joseph Lead company, Bonne Terre, Missouri.

Mine La Motte company, Mine La Motte, Missouri.

*In Europe.**—The lead production of Europe amounts to nearly 500,000 tons annually.

The largest producer is Spain. Home ores mainly are smelted there. The provinces in which most lead is smelted are Murcia, Jaen, Almeria and Cordoba. The principal smelting works are those of the Penarroya company, situated at Linares, which produces about 2000 tons a year.

In Germany, the principal works are the Mechernicher Bergwerks-verein, at Mechernich, producing about 24,000 tons; the Stolberg company at Aix la Chapelle, which produces about 18,000 tons of lead; the Rhenische Nassauische Bergwerks and Huttenactiengesellschaft at Holtzappel, producing about 7000 tons; the Emser Blei und Silberwerks, and S. B. Goldschmidt near Ems, each producing about 5000 tons. The government has smelting works at Clausthal, Lautenthal, Altenau, St. Andreasberg, Oker and Freiberg, as well as at Friedrichshutte in Silesia. The Georg von Gieschenerben are at Breslau.

In Belgium, there are but few works, and these subsist entirely on imported ores. The most important are the works at Hoboken near Antwerp.

In Great Britain, there are some large smelting works at Newcastle, also at Bristol, Chester and London.

In Austria and Austro-Hungary, the chief points of activity are in Carinthia, where the Bleiberg company, Count Henckel von Donnersmack and the government, jointly smelt about 5500 tons of lead annually.

In Italy, the Pertuloso works, which produce some 14,000 tons, are the only important ones in operation, the Cogoleto works having been closed for the last ten years. In Greece, the French Laurium company

* For many of the figures of production of European lead works, the writer is indebted to notes kindly supplied by Mr. John N. Judson, of St. Louis, who has made a special study of th subject.

and the Greek Laurium company produce about 2200 tons and 8500 tons, respectively.

ZINC SMELTING WORKS.

In the United States.—The production of zinc in the United States amounts to about 84,000 tons per year. It has been found impracticable to obtain many figures of outputs of the individual works in this country, as the managers, in many cases, decline to make the information public. We have, therefore, in the following list, used the productions of the groups given in the Mineral Industry, vol. II.

The following is a practically complete list of the smelters in the United States, prepared from information kindly furnished by Mr. Chas. Kirchoff:

EASTERN AND SOUTHERN STATES.—Production 1892, 14,733 tons; 1893, 10,708 tons.

Edes, Mixter & Heald Zinc company, Plymouth, Massachusetts. and Knoxville, Tennessee.
Delaware Metal Refining Company, Philadelphia, Pennsylvania.
Friedensville Zinc company,* Friedensville, Pennsylvania.
New Jersey Zinc & Iron company,* Newark, New Jersey.
Passaic Zinc company,* Passaic, New Jersey.
Lehigh Zinc & Iron company,* Lehigh, New Jersey.
Bertha Zinc & Mineral company, Pulaski, Virginia.
Wyeth Lead & Zinc company, Wyethville, Virginia.

ILLINOIS AND INDIANA.—Production 1892, 30,227 tons; 1893, 29,725 tons.

Matthiessen & Hegeler Zinc company, Lasalle, Illinois.
Illinois Zinc Company, Peru, Illinois.
Collinsville Zinc company, Collinsville, Illinois.
Cherokee Zinc works, Winona, Illinois.
Columbian Zinc company, Marion, Indiana.

MISSOURI.—Production 1892, 16,169 tons; 1893, 13,727 tons.

Empire Zinc company, Joplin.
Glendale Zinc company, St. Louis.
R. Lanyon & Co., Nevada.
Rich Hill Zinc company, Rich Hill.

KANSAS.—Production 1892, 22,953 tons; 1893, 22,085 tons.

Girard Zinc company, Girard.
R. Lanyon, Pittsburg.
W. & J. Lanyon, Pittsburg.
S. H. Lanyon & Bro., Pittsburg.
Pittsburg & St. Louis Zinc company, Pittsburg.
Cherokee Zinc company, Pittsburg and Weir City.
Granby Mining and Smelting company, Pittsburg.
Scammond Zinc company, Scammond.
American Spelter company, Galena.

*Manufacture zinc oxide in addition.

It will be noticed that all of the works are situated in or contiguous to large coal fields. Those in Illinois, Missouri and Kansas are supplied almost wholly by Missouri and Kansas ores, and will be described in more detail in chapter XIII.

In Europe.—In Europe, the production of zinc constitutes a large industry. The annual production is now about 300,000 tons, and this could be increased considerably if desired. In fact, it has been found necessary for the zinc smelters abroad to form a syndicate and limit the production to keep the price from falling to an unprofitable figure. Many of the following figures are derived from the Mineral Industry.

The largest works are those of the Vieille Montagne Zinc company. While the main offices and works of this company are in Belgium, they operate mines, smelters and factories in various parts of France, Germany, Italy, Spain, Sweden and Africa. They produce annually over 60,000 tons, of which about 58,000 tons are rolled into sheet zinc, and the remainder, with a few thousand tons more which is purchased, is turned into zinc white. Fully 75 per cent of the sheet zinc is used for roofing. This company is by far the largest in the world, producing three-quarters as much zinc as the whole of the United States. Next come the following large producers in Belgium and the Rhine districts: The Stolberg company, producing about 13,500 tons; the Austro-Belge company, about 8500 tons; G. Dumont et Freres, 5200 tons; Rhein-Nassau company, 8000 tons, and the Bleiberg company 6500 tons.

In Silesia, the Schlesiche-Actiengesellschaft is the largest producer, turning out annually about 23,000 tons, of which the greater part is rolled into sheet zinc and used for roofing purposes. The other important ones are the G. Von Giesche, 15,000 tons, and the Herzog Von Ujest, 16,500 tons.

In Great Britain, the total production is about one-third of the consumption. The principal scene of activity in the smelting industry is at Swansea, in Wales. Here, there a dozen or more works, which produce annually, amounts ranging from 500 to 7000 tons of metal. The largest concern is that of the Vivian company, which produces about 7000 tons of spelter.

In Spain and France, outside of the works of the Vieille Montagne, there is but one company that smelts zinc, namely, the Societe Asturienne, which produces annually about 16,000 tons.

The production of zinc in Austria and Poland is small, reaching about 6000 tons in the former country, produced by small companies

that smelt about 1000 tons each. In Poland, the production is about 3500 tons.

THE MANUFACTORIES OF LEAD AND ZINC.

In the United States.—Fully one-half of the lead made in the country is used in the manufacture of white lead. The following companies are the principal producers:

LIST OF PRINCIPAL WHITE LEAD WORKS IN THE UNITED STATES.*

American White Lead company, Louisville, Kentucky.
Anchor White Lead works, Goshorn Bros., Cincinnati, Ohio.
Armstrong & McKelvy, Pittsburg, Pennsylvania.
Atlantic White Lead, Robert Colgate & company, New York City.
Beymer, Bauman & company, Pittsburg, Pennsylvania.
The Bradley White Lead company, New York City.
Brooklyn White Lead company, New York City.
Collier White Lead company, St. Louis, Missouri.
Cornell, S. G., & Sons, Buffalo, New York.
Davis-Chambers Lead company, Pittsburg, Pennsylvania.
Eckstein White Lead company, Cincinnati, Ohio.
Fahnestock, Haslit & Schwartz, Pittsburg, Pennsylvania.
Fahnestock White Lead company, Pittsburg, Pennsylvania.
Jewett & Sons, New York City.
Kentucky White Lead company, Louisville, Kentucky.
Lewis, John T., & Bros, Philadelphia, Pennsylvania.
Maryland Lead company, Baltimore, Maryland.
Missouri White Lead company, St. Louis, Missouri.
Morley, J. H. & company, Cleveland, Ohio.
McBirney & Johnson company, Chicago, Illinois.
Salem Lead company, Salem, Massachusetts.
Shipman, D. B., Chicago, Illinois.
Southern White Lead company, St. Louis and Chicago.
St Louis Lead & Oil company, St. Louis, Missouri.
The Ulster Lead company, Saugerties, New York.
The Union White Lead Manufacturing company, New York City.
Western White Lead company, Philadelphia, Pennsylvania.

Among the principal manufacturers of sheet, pipe and shot are: the American Shot & Lead company, Chicago; the National Lead company, New York; Tatham & Brother, New York City; Colwell Lead company, New York City; Raymond Lead company, Chicago; and James Robertson Manufacturing company, Baltimore. E. W. Blatchford & company, Chicago, and L. M. Rumsey of St. Louis, make sheet and pipe but not shot.

While considerable effort has been made to secure a full list of the principal users of spelter, it is impossible to cherish any idea of completeness. There are so many small foundries and machine shops

*Extracted from a circular of the National White Lead company.

where brass is made in small quantities, that the list of them, even if it were possible to prepare, would be very voluminous and of small value.

There are but two companies producing rolled zinc in this country, the Matthiessen & Hegeler Zinc company, of LaSalle, Illinois, and the Illinois Zinc company, of Peru, Illinois. These two turn out approximately 15,500 tons annually.

The manufacturers of galvanized iron and barb wire in the United States are as follows: *

Merchant & company, Philadelphia, Pennsylvania.
McDaniels & Harvey, Philadelphia, Pennsylvania.
Jos. E. Strauss & company, Philadelphia, Pennsylvania.
Marshall Bros. & company, Philadelphia, Pennsylvania.
Cambria Iron company, Philadelphia, Pennsylvania.
Phœnix Galvanizing company, Pittsburg, Pennsylvania.
Apollo Iron & Steel company, Pittsburg, Pennsylvania.
Oliver & Roberts Lead company, Pittsburg, Pennsylvania.
Jas. McQuistan & company, Pittsburg, Pennsylvania.
Morehead-McCleane company, Pittsburg, Pennsylvania.
E. E. Converse, McKeesport, Pennsylvania.
Consolidated Steel & Wire company, Rankin, Pennsylvania.
Consolidated Steel & Wire company, Chicago, Illinois.
Consolidated Steel & Wire company, St. Louis, Missouri.
St. Louis Stamping company, St. Louis, Missouri.
Bannantine Galvanizing company, St. Louis, Missouri.
New Jersey Wire Cloth company, Trenton, New Jersey.
Clinton Wire & Cloth company, Trenton, New Jersey.
Trenton Iron company, Trenton, New Jersey.
J. A. Roebling Sons & company, Trenton, New Jersey.
Buch-Thorn Fence company, Trenton, New Jersey.
W. T. Simpson, Cincinnati, Ohio.
Ætna Standard Iron & Steel company, Bridgeport, Ohio.
Seymour Manufacturing company, Seymour, Connecticut.
Washburn & Moen Manufacturing company, Worcester, Massachusetts.
Washburn & Moen Manufacturing company, Waukegan, Illinois.
John McVoy & company, Chicago, Illinois.
Superior Barbed Wire company, DeKalb, Illinois.
Whittaker Iron company, Wheeling, West Virginia.
Riverside Iron company, Wheeling, W. Virginia.
American Barbed Wire company, Cleveland, Ohio.
Reeves Iron company, Canal-Dover, Ohio.
Cambridge Iron & Steel company, Cambridge, Ohio.

* This, and the following lists of manufacturers of zinc products, were kindly furnished by Mr. W. P. Coleman, Vice-President of the Missouri Metal company.

Falcon Iron & Nail company, Niles, Ohio.
Cincinnati Corrugating company, Piqua, Ohio.
Cincinnati Barbed Wire company, Cincinnati, Ohio.
W. S. Taylor Wire Works, Cleveland, Ohio.
Cleveland Rolling Mill company, Cleveland, Ohio.
Button Iron & Steel company, Cleveland, Ohio.
Michigan Wire & Iron company, Detroit, Michigan.

The following are engaged in the manufacture of brass, brass-wire, electrical machinery, etc.:

American Brass & Copper company, Ansonia, Connecticut.
Benedict-Burnham Manufacturing company, Waterbury, Connecticut.
Coe Brass Manufacturing company, Stonington, Connecticut.
Buckeye Brass company, Dayton, Ohio.
Wm. Powell company, Cincinnati, Ohio.
M. M. Buck & Company, St. Louis, Missouri.
L. M. Rumsey Manufacturing company, St. Louis, Missouri.
Manhattan Brass company, New York city.
Western Electric company, New York city.
Western Electric company, Chicago, Ill.
L. Wolff Manufacturing company, Chicago, Ill.
Chicago Brass company, Chicago, Ill.
Detroit Copper & Brass R. M. company, Detroit, Mich.

The following list consists of consumers who use zinc for various purposes, besides those mentioned above:

John Davol & Sons, New York City, importers of metals.
Brucek & Cook, New York City, importers of metals.
Hendrichs Bros., New York City, importers of metals.
Aermotor Company, Chicago, wind-mills.
Geuder, Paescheke company, Milwaukee, house-furnishing goods.
H. H. Palmer Company, Rockford, Ill., churns.
Hoyt Metal Company, St. Louis, alloys.

There are a few other consumers which are not mentioned, such as the silver refining works, which use small quantities individually. Some of the zinc smelters make the zinc elements for the batteries used by the telegraph companies.

In Europe.—As has been stated, the largest single use of lead is for the manufacture of white lead. In Europe, this industry is very widely spread. Germany probably produces 50,000 tons, much of which is made by modifications of the Dutch process, which modifications are kept secret. Considerable quantities are made by a more rapid process, however, and are for export trade. England produces about as much white lead as Germany. It is manufactured mainly at New-

castle-on-the-Tyne, London, Chester and Bristol, Glasgow and some other places. Italy probably produced considerable white lead at Genoa, Cogoleto, Naples and Milan, there are a few works now in operation at Naples and Milan; but the total output is probably less than 4000 tons. The Netherlands produce about 500 tons altogether, all of which is consumed at home.

After some inquiry and correspondence, it was found impracticable to obtain any detailed information regarding the manufacture of zinc in Europe. By far the largest portion is used in the form of sheet for roofing and similar purposes, as already stated. A considerable portion of the remainder is turned into zinc white. The manufacture of these articles is usually carried on in connection with the various smelting works.

Markets.—The American markets for lead are principally New York, Chicago, St. Louis and Baltimore. The same points, with the addition of Philadelphia, Pittsburg and Cleveland, are the main markets for spelter. At these places, the smaller consumers buy from the commission merchants; most of the larger consumers, however, purchase direct from the smelter.

STATISTICS AND PRICES.

PRODUCTIONS.

World's Productions.—In the accompanying tables are given the productions of lead and zinc and their ores in all countries.

It has been found impracticable, with the time and means at our disposal, to obtain much detailed information previous to 1860. Consequently, for periods before that year, only the average annual rate of production has been inserted, when it could be ascertained. Since 1860, however, the figures of production have been more carefully kept, and are more accessible.

Many countries simply mine these ores and export them to other countries for reduction. Other countries mine but insignificant quantities, but have large smelting and manufacturing industries. In comparing tables of production that have been published, confusion is liable to arise from the fact that some of them give the output of the smelters of the respective countries, while others give the metal contents of the ores mined.

In the accompanying tables, we have given in adjoining columns both the ore mined in the country and the total amount of metal produced whether from home or foreign ores.

The metal production of a country, therefore, must not be considered as having necessarily any relation to the ore mined there. The figures of production are given in short tons of 2000 lbs., such being the commonly accepted unit in this country.

In preparing these tables the writer has consulted various authorities, principally: Whitney's Metallic Wealth [*234*]; Phillips' Ore Deposits [*168*]; Hunt's British Mining [*116*]; Fuchs and DeLaunay's Treatise on Ore Deposits [*91*]; Statistics of the Metallgesellschaft, Frankfort am Main [*212*]; Henry R. Merton's Statistics of the World's Productions of Zinc; Mulhall's Dictionary of Statistics [*151*]; Hague's Report on the Paris Exposition [*94*]; the various volumes of the United States Mineral Resources and the volumes of the Mineral Industry [*195*], as well as many miscellaneous articles in the Trans. Am. Inst. Min. Eng. and in scientific periodicals. Because of the substantial agreement between the figures given in the Mineral Industry and those of the best authorities, as well as the fact of the later date of those contained in the Mineral Industry, preference has been given

WORLD.

l.	Norway. Ore.	Norway. Metal.	Russia. Ore.	Russia. Metal.	Spain. Ore.	Spain. Metal.	Sweden. Ore.	Sweden. Metal.	United States. Ore.	United States. Metal.
18	...	...	...	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...	...	...	...
18	...	...	...	2,800	...	...	...	...	...	...
18	...	...	...	3,500	...	...	...	...	...	...
18	...	...	...	2,000	...	...	...	...	...	...
18	...	...	...	2,015	...	...	...	...	...	...
18	...	...	...	...	...	...	7,947	...	...	...
18	...	...	...	...	...	...	9,384	...	...	...
18	...	...	...	...	...	...	9,958	...	...	...
18	...	...	...	...	...	...	14,606	...	...	...
18	...	...	...	3,393	...	...	27,599	...	...	...
18	...	...	...	...	...	...	22,868	...	...	...
1	...	...	21,758	3,245	95,916a	...	20,713	...	...	...
1	...	...	27,486	3,569	144,873a	...	26,275	...	...	...
1	...	...	44,444	3,984	125,116a	...	35,000	...	...	...
1	...	...	47,888	4,154	125,203	...	31,072	...	...	...
1	...	...	47,822	/ 2,998	118,272	3,480	35,474	...	...	...
1	...	...	78,984	3,387	98,424	3,240	36,644	...	...	...
1	...	...	79,110	3,709	111,306	3,289	30,258	...	...	7,343g
1	...	...	110,538	4,533	117,396	3,511	30,979	...	...	10,000h
1	...	...	72,486	4,379	110,445	4,224	34,774	...	...	15,833g
1	...	...	67,502	5,100	119,041	4,784	39,165	...	...	16,000h
1	...	...	...	5,110	78,227	4,168	44,064	...	...	17,500h
1	...	...	...	4,020	78,884	4,162	44,966	...	...	19,000h
1	...	...	...	4,764	66,128	4,190	48,310	...	...	21,000h
1	...	...	...	4,730	55,483	4,632	47,806	...	...	23,239g
1	...	...	...	5,006	47,334	7,753	48,303	...	...	30,000h
1	330*	...	106,934e	4,809	63,067	8,060	50,998	...	...	33,765g
1	220*	...	91,510e	4,200	59,750	7,543	50,000	...	...	36,872g
1	630*	...	30,800e	5,037	54,948	4,730	49,496	...	...	38,544g
1	340*	...	49,600e	4,619	50,173	4,682	53,571	...	...	40,688g
1	...	...	41,900e	3,992	43,872	4,715	54,654	...	...	42,641g
1	...	...	...	4,144	76,078	5,897	50,782	...	...	50,840g
1	1,700*	...	50,700	4,058	81,976	5,631	54,986	...	...	55,903g
1	3,600*	...	...	4,154	79,133	6,217	65,358	...	...	58,860g
1	4,340*	...	48,690	4,051	89,744	6,515	68,184	...	...	67,342
1	538	...	52,249	3,938	...	6,236	67,685	...	...	80,262
1	...	...	...	5,782d	...	6,583	60,508	...	...	84,082
1	...	...	...	5,118d	...	...	...	...	...	76,255

d on since 12th century, but small production until 1800. Mines are becoming
Y.—Mining began in 14th or 15th century, but little work done until the beginning
, the productions of ore are from the Mineral Industry, and those of metal (total
century, and probably before that time.... ITALY.—Mining began about 1860.....
Henry C. Merton; *e*, Fuchs and DeLaunay [*91*]; remainder, Mineral Industry......
l Industry; 1890-96 from returns to the Eng. and Min. Jour. by producers.

exico.	Russia.		Spain.		Sweden.		Turkey.		United States.	
Metal	Ore.	Metal.	Ore.	Metal.	Ore.	Metal.	Ore.	Metal	Ore.	Metal.
....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	33,000*a*	....	....	....	....	....	1,500
....	....	740	....	30,800*a*	....	55*a*	....	....	....	12,250
....	....	1,000	....	30,800*a*	....	45*a*	....	....	....	24,700
....	....	1,300	250,000	33,600*a*	....	200*a*	....	....	....	16,880
....	....	1,205	359,292	....	....	....	....	....	....	15,600
....	....	....	394,168	....	....	....	....	....	....	14,100
....	....	....	305,225	....	....	....	....	....	....	14,200
....	....	....	341,709	....	....	....	....	....	....	14,800
....	....	....	330,419	....	....	....	....	....	....	15,300
....	....	1,800	319,338	....	....	....	....	....	....	14,700
....	....	....	329,427	....	....	....	....	....	....	16,100
....	40,133	1,907	405,413	....	....	452	....	....	....	15,200
....	51,756	1,804	382,115	....	....	433	....	....	....	16,400
....	56,666	1,172	355,910	....	....	566	....	....	....	17,500
....	38,184	1,818	388,192	....	13,471	412	....	....	....	17,830
....	39,132	1,926	471,087	101,452	13,201	98	....	....	....	20,000
....	34,042	1,334	448,395	111,960	10,563	56	....	....	....	25,880
....	34,006	1,096	281,081	109,985	10,660	28	....	....	....	42,540
....	37,791	1,366	371,444	117,153	13,452	60	....	....	....	52,080
....	28,519	1,194	372,710	131,808	12,270	60	....	....	....	59,540
....	37,833	1,288	418,496	140,573	10,387	50	....	297	....	64,070
....	....	1,548	374,726	89,109	9,822	38	....	....	....	81,900
....	....	1,535	374,112	98,761	9,942	50	....	....	....	91,360
....	....	1,496	379,338	99,346	15,168	50	....	....	....	92,780
....	....	1,263	353,725	88,212	14,322	217	....	297	....	97,825
....	....	1,087	405,292	99,969	12,964	421	....	551	....	117,085
....	36,600	632	401,481	97,397	15,127	268	....	827	....	132,890
16,400*	31,400	599	335,842	109,495	15,385	99	....	650	....	143,957
16,400*	32,000	698	393,826	91,846	17,557	401	....	....	....	139,897
19,290	33,000	787	315,097	97,591	16,385	296	....	....	....	129,412
17,600	....	856	402,917	116,693	15,338	217	....	....	....	135,629
19,960	41,900	1,088	532 976	205,816	17,217	311	....	....	....	160,700
33,186	41,300	869	595,266	258,930	11,775	315	....	....	....	180,555
31,312	....	625	544,427	194,952	18,387	280	....	....	....	182,967
24,269	....	922	545,385	196,199	16,522	369	....	....	....	160,189
33,270	33,000	615	356,692	182,997	16,586	347	....	....	....	197,113
52,406	....	660*	372,281	193,070	21,822	888	....	....	....	209,411
66,731	....	....	....	207,829	....	....	....	....	....	195,948

during the Middle ages. These productions from the Mineral Industry agree closely with those
l consumption......FRANCE.—Mining prosecuted by the Romans and at intervals since. Produc-
te .....GREAT BRITAIN.—Mines worked since the Roman invasion and probably before. Statistics
00,000 tons metal produced in the 5th and 6th centuries B. C. Since beginning of the Christian era
t little mining done. *e*, Monroe [148]; *f*, Phillips [165]; *g*, Rein [157] ....MEXICO.—Silver mining
unay......SPAIN.—Mining dates from time of Phœnicians. Figures of production of ores include
eral Resources; 1889, 11th Census; 1890-93, the Mineral Industry.

to these, and in most cases they have been used, the exception being where figures derived from local sources seemed more authoritative, or where no figures were given for the respective countries.

Productions in the United States.—The published statistics of the productions of lead and zinc in the United States are very imperfect. Previous to 1889 the figures from the various states are largely estimates. When records have been preserved with any care at all, the productions of adjoining states have often been combined, so that the individual state productions cannot be determined. From the year 1889 on, the figures are more reliable, through Mr. Rothwell's undertaking to trace the argentiferous lead ores sent to the refining works back to the states and territories from which they originally came. The figures of production for Missouri, Kansas, Wisconsin, Illinois and Iowa, particularly, have been reported as the "production of the Mississippi valley," and the productions of the individual states have been hard and in many cases impossible to obtain.

It has been a defect of previously published tables of statistics, that the productions of lead *ores* have seldom been included. We have endeavored, so far as the time and means at our disposal would allow, to collect from various sources the figures of production of both metal and ore. For convenience of reference, these have been arranged in adjoining columns in the same table. Here, as with the table of world productions, the figures of metal represent the outputs of the smelters, and not the metalliferous contents of the ore mined in any one state, unless noted to the contrary.

Similar remarks might be made concerning the figures of zinc ores and metallic zinc. More attention has been paid, however, to the preservation of figures of ore production.

TABLE OF PRODUCTIONS OF LEAD ORE AND METAL IN THE UNITED STATES.

(Figures of Production in tons of 2000 lbs)

	Wisconsin.		Missouri.		Kansas.		Colorado.		New Mexico.		Utah.		Nevada.		Ariz. & Cal		Idaho.		Montana.	
	Ore.	Metal.	Ore.	Metal.	Ore.	Met'l	Ore.	Metal	Ore.	Metal.	Ore.	Metal.	Ore.	Metal.	Ore.	Metal.	Ore.	Metal.	Ore.	Metal.
	1862-69 5,730	1821-71 540,975	1720-1869 840,200	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
1870	....	....	9,300	....	....		....	....	....	....	....	....	....	....	....	....	....	....	....	....
1871	....	....	11,900	....	....		....	....	....	....	....	....	....	....	....	....	....	....	....	....
1872	....	7,000	13,100	....	....		....	....	....	....	....	....	....	....	....	....	....	....	....	....
1873	....	7,000	20,500	....	....		....	56	....	....	....	15,000	....	....	....	....	....	....	....	....
1874	....	5,400	25,800	....	....		....	312	....	....	....	20,000	....	....	....	....	....	....	....	....
1875	....	5,400	27,700	....	....		....	818	....	....	....	19,000	....	....	....	....	....	....	....	....
1876	....	4,500	36,000	....	3000a		....	667	....	....	....	25,000	....	....	....	....	....	....	....	....
1877	....	6,417	31,600	....	....		....	897	....	....	....	27,000	....	19,724	....	....	....	....	....	....
1878	....	4,492	29,900	....	....		....	6,669	....	....	....	21,000	....	31,065	....	....	....	....	....	....
1879	....	2,800	30,800	....	....		....	23,674	....	....	....	14,000	....	22,805	....	....	....	....	....	....
1880	....	....	32,800	....	10,684b		....	35 674	....	....	....	15,000	....	16,659	....	....	....	....	....	....
1881	....	....	39,800	....	....	....	....	40,547	....	....	....	24,000	....	12,826	....	....	....	800	....	....
1882	....	....	38,200	....	....	....	....	55,000	....	....	....	30,000	....	8,590	....	....	....	5,000	....	4,100
1883	....	....	32,700	....	....	....	....	70,557	....	2,400	....	29,000	....	6,000*	....	3,200	....	6.000	....	4,900
1884	....	....	26,800	....	....	....	....	63,165	....	6,000	....	28,000	....	4,000	....	4,800	....	7,500	....	6,900
1885	....	....	32,900	....	....	....	....	55,000	....	5,000	....	28,000	....	3,500	....	4 000	....	....	....	6,000*
1886	....	....	31,000	....	2 962c	....	....	59,000	....	5,000	....	21,500*	....	3,400	....	3,500*	..	17,500	....	5,500*
1887	....	....	27,500	....	3,200d	...	....	61,000	....	4,500	....	18,750*	....	3,400	....	3,300*	....	20,000	....	7,000
1888	....	....	42,000	....	2,642[illegible]	....	....	65,500	....	4,500	....	17,500*	....	2,400	....	2,500*	....	....	....	8,500

1889	1,678	....	46,000	....	3,617e	......	......	69,000	......	4,764	......	16,500	....	1,950	....	3,200	....	23,172	......	10,188
1890	....	....	43,600	....	4,174f	......	......	54,500	......	5,910	......	15,000*	......	1,500*	....	1,500	....	25,000*	....	10,000*
1891	....	....	45,600	....	3,602f	......	......	64,000	....	5,330	......	16,000*	....	2,500	......	2,000	.. ..	38,568	....	14,127
1892	....	....	50,400	....	7,188f	......	....	61,500	....	5,895	....	22,000	....	3,000	...	2,500	......	33,000*	....	12,858
1893	....	....	42,000	......	....	....	......	42,698	....	6,869	....	26,454	......	3,041	....	2,405	....	32,263	......	8,348

MAINE, NEW HAMPSHIRE, MASSACHUSETTS, CONNECTICUT AND NEW YORK.—Some lead mining in early years (after 1650), now practically none ......PENNSYLVANIA.—Little lead mining, no statistics available .... MARYLAND —One mine operating in 1890, no statistics .....VIRGINIA.—Mining began in 1621: some done now; no figures .... NORTH CAROLINA – But little mining done. Production of lead ore in 1875 estimated at 40 to 50 tons a month .....WISCONSIN.—Mining commenced about 1800, and reached its maximum between 1840 and 1850. Productions of metal are metal contents of ores mined in state. Statistics of ore not obtained .... ILLINOIS AND IOWA —Mining commenced about the same time as in Wisconsin. Few statistics available. In 1880 the census gives for Illinois 723 tons lead ore, and in 1889, 173 tons. Iowa has produced very little .....KENTUCKY.—Some little desultory mining done; no statistics......MICHIGAN AND MINNESOTA —No mining done......MISSOURI.—Figures derived from data of chapter xiii..... KANSAS.—Mining began about 1868. *a*, Prof. Mudge [*150*]; *b*, Tenth U. S. Census; *c*, U. S Mineral Resources; *d*, State Mine Inspector's Report; *e*, Eleventh U. S. Census; *f*, C. D. Dana, Galena (Kans.), Times..... ARKANSAS.—Production very small. No statistics......COLORADO —Little mining done before 1870, but has increased rapidly since.... .NEW MEXICO.—No statistics available before 1883......UTAH —Mining began about 1870; has been actively prosecuted since......NEVADA —Lead mining practically began in 1869. The maximum was reached about 10 years later, and since then it has declined. No statistics available before 1877......ARIZONA AND CALIFORNIA.—The productions of these states are combined. Main portion comes from Arizona, California producing insignificant amounts..... IDAHO.—Mining began about 1860, increased slowly until 1882. No statistics until 1880 .... MONTANA.—Mining began about 1850, but with small productions until within the last few years......THE DAKOTAS.—Small deposits mined during recent years. Production 1887, 1000 tons lead; 1889, 116 tons; 1892, small amounts.

Where not otherwise specified, the figures of productions have been taken from the Mineral Industry.

*Estimated.

TABLE OF PRODUCTIONS OF ZINC ORES AND METAL IN THE U. S.

(Figures of Production in tons of 2000 pounds.)

Year.	New Jersey.		Wisconsin.		Illinois.		Missouri.		Kansas.	
	Ore	Metal.	Ore.	Metal.	Ore	Metal.	Ore.	Metal	Ore.	Metal.
	1853-54	......	1860-69	......	...	......	1860-69	......	......	......
	6,450	......	20,317	......	..	......	200	......	......	......
	1868	......	......	......	...	......	......	......	......	......
	25,000*	......	......	......	..	......	......	......	......	......
1870	......	......	5,912	......	..	......	3,100	......	......	......
1871	22,000*	......	12,961	......	..	......	3.500	......	......	......
1872	......	......	21,976	......	...	......	6,300	......	......	......
1873	17,500	......	17,814	......	..	......	7,500	......	......	......
1874	18,500	......	17,313	......	..	......	11,700	......	......	......
1875	......	......	16,208	......	..	......	17,100	......	......	......
1876	......	......	14,675	......	..	......	23,600	......	......	......
1877	......	......	......	......	...	......	25,600	......	......	......
1878	14.687	......	......	......	...	......	27,900	......	......	......
1879	21,937	......	16,500*	......	...	......	30,600	......	......	......
1880	28,311	......	4,617	......	...	......	34,500	......	7,248a	......
1881	49,178	......	......	......	...	......	47,800	......	14,828b	......
1882	40,188	......	......	......	..	18,201	46,700	2,500	16,552b	7,366
1883	56,085	......	......	......	..	16,792	47,500	5,730	16,891b	9.010
1884	40,094	......	......	......	....	17,594	56.900	5,230	18,985b	7,859
1885	38,526	......	......	......	..	19,427	53,700	4,677	22,203b	8,502
1886	43,877	......	......	......	..	21,077	63 000	5,870	27,210b	8,932
1887	50,220	......	......	......	..	22,279	75,100	8,660	27,887b	11,965
1888	46,377	......	......	......	..	22,445	83,500	13,465	27,275b	10,432
1889	56,154	......	24,832	......	....	23,860	82,400	11,077	39,575c	18,658
1890	49,618	......	......	......	..	26,279	100,200	18,530	21,675d	16.880
1891	76,032	......	......	......	..	28,660	123,300	16,205	20,642l	21,460
1892	77,293	......	......	......	..	30,227a	132,400	16,169	23,812d	21,953
1893	....	......	......	......	..	29,725a	108,800	13 737	......	22,085

Notes.—NEW HAMPSHIRE, CONNECTICUT and NEW YORK.—Small deposits of zinc occur, but have not been worked. PENNSYLVANIA.—Mining began in 1850. No statistics available; total production estimated 500,000 and 1,000,000 tons ore.... NEW JERSEY.—Mining began in 1850. Statistics from N. J. Geological Survey. MARYLAND.—Little mining done; in 1880, 72 tons of ore produced. VIRGINIA.—Mining commenced about 1870. No statistics obtained; output probably 15,000 to 25,000 tons of zinc ore per annum.... NORTH CAROLINA.—Practically no production. TENNESSEE. Mining has been carried on over 25 years, but no statistics are available...... WISCONSIN.—Zinc mining began in 1860. Statistics from Geological Survey of Wisconsin. Recent years no figures available. ILLINOIS and IOWA.—Mining began about 1860. Much ore produced. No figures of ore production available in 1880, according to the Census. 3000 tons of ore produced in Illinois, but none mentioned in Iowa. In 1889 the Census gives 450 tons of ore from Illinois.... MISSOURI.—Ore productions from data of chapter XIII. KANSAS.—Mining began about 1875. *a* Tenth Census. *b* Matthiessen and Hegeler. *c* Eleventh Census. *d* C. T. Dana, Galena (Kas.) Times. ARKANSAS.—Little or no zinc ore shipments; production 1889, 130 tons; 1892, 350 tons. ROCKY MOUNTAIN—GREAT BASIN REGION.—No zinc ore has been produced for market except in New Mexico. Shipment to Jan., 1894, 1355 tons. Mines now closed.

Unless otherwise noted, productions are taken from the Mineral Industry.

* Estimated.

IMPORTS AND EXPORTS.

The United States has, from time to time, imported and exported more or less of these metals, although the amounts either way were not large. It has been suggested during the last few years that a profitable export trade in these metals or in the ores could be worked up, and a special consular report has just been issued, containing the opinions of the consular representatives of this government in foreign countries on this subject [*138*]. Tables of the amount of lead and zinc imported into and exported from the United States are introduced here as bearing on this subject. They are all extracted from the volumes of the Mineral Industry.

IMPORTS OF LEAD FOR CONSUMPTION IN THE UNITED STATES.

[Calendar years ending December 31 from 1886 to 1890; previous years end June 30.]

Year.	Ore and Dross.		Pigs and Bars.		Sheets, Pipe, and Shot.		Old and Scrap.		Manufactures. n. e. s., Value.	Total Value.
	Pounds.	Value.	Pounds.	Value.	Pounds.	Value.	Pounds.	Value.		
1867	611	$25	65,322,923	$2,812,668	185,825	$9,560	1,255,233	$53,202	$6,222	$2,828,475
1868	6,945	239	63,254,677	2,668,915	142,137	7,229	2,465,575	101,586	6,604	2,682,987
1869	....	....	87,865,471	3,653,481	307,424	15,531	2,983,272	123,068	18,885	3,687,897
1870	5,973	176	85,895,724	3,530,837	141,681	6,879	3,756,785	150,379	10,444	3,548,336
1871	316	10	91,496,715	3,721,096	86,712	4,209	2,289,688	94,467	8,730	3,734,045
1872	32,331	1,425	73,086,657	2,929,623	15,518	859	4,257,778	171,324	20,191	2,952,098
1873	....	....	72,423,641	3,233,011	525	62	3,545,098	151,756	21,503	3,254,576
1874	....	....	46,205,154	2,231,817	30,219	1,349	395,516	13,897	36,484	2,269,650
1875	13,206	320	32,770,712	1,559,017	58	4	382,150	13,964	25,774	1,585,115
1876	....	....	14,329,366	682,132	20,007	1,204	265,860	9,534	27,106	710,442
1877	1,000	20	14,583,845	671,482	16,502	1,242	249,645	8,383	1,041	673,785
1878	....	....	6,717,052	294,233	15,829	963	106,342	3,756	113	295,309
1879	....	....	1,216,500	42,983	3,748	209	42,283	1,153	930	44,122
1880	....	....	6,723,706	246,015	1,120	54	213,063	5,262	20,976	*268,198
1881	5,981	97	4,322,068	159,129	900	65	123,018	2,729	111,890	276,443
1882	21,698	500	6,079,304	202,603	1,469	99	220,702	5,949	62,139	268,070
1883	600	17	4,037,867	130,108	1,510	79	1,094,133	31,724	86,703	222,856
1884	419	13	3,072,738	85,395	15,040	630	160,356	4,830	127,949	245,711
1885	4,218	57	5,862,474	143,103	971,951	22,217	4,866	106	466,755	636,962
1886	715,588	9,699	17,582,298	491,810	27,357	1,218	24,726	882	559,284	1,061,617
1887	153,731	21,487	7,716,783	219,770	27,941	1,286	136,625	4,323	364,740	†608,165
1888	88,870	2,468	2,582,236	69,891	23,103	1,202	33,100	904	407,839	585,723
1889	328,315	7,468	2,773,622	76,243	35,859	1,417	50,816	1,494	425,144	511,176
1890	493,463	12,947	19,336,233	593,671	68,314	3,338	*a*	*a*	1,210,387	1,821,837
1891	105,898	6,721	3,392,562	104,184	334,179	12,406	....	....	2,744,122	2,867,633
1892	....	....	....	....	....	....	....	....	....	4,570,233

EXPORTS OF LEAD AND MANUFACTURES OF LEAD, OF DOMESTIC PRODUCTION.

Year.*	Manufactures of Lead. Pounds.	Manufactures of Lead. Value.	Pewter and Lead. Value.	Bars, Shot, etc. Pounds	Bars, Shot, etc. Value.	Total Value.
1790	13,440	$810				$810
1803	900					
1804	19,804					
1805	8,000					
1808	40,583					
1809	126,537					
1810	172,323					
1811	65,497					
1812	74,875					
1813	276,940					
1814	43,600					
1815	40,245					
1816	35,844					
1817	111,034	9,993				9,993
1818	281,168	22,493				22,493
1819	94,362	7,549				7,549
1820	25,699	1,799				1,799
1821	56,192	3,512				3,512
1822	66,316	4,244				4,244
1823	51,549	3,098				3,098
1824	18,604	1,356				1,356
1825	189,930	12,697				12,697
1826	47,337	3,347	$1,820			5,167
1827	50,160	3,761	6,183			9,944
1828	76,882	4,184	5,545			9,729
1829	179,952	8,417	5 185			13,602
1830	128,417	4,831	4,172			9,003
1831	152,578	7,068	6,422			13,490
1832	72,439	4,483	983			5,466
1833	119,407	5,685	2,010			7,695
1834	13,480	805	2,224			3,029
1835	50,418	2,741	433			3,174
1836	34,600	2,218	4,777			6,995
1837	297,488	17,015	3,132			20,147
1838	375,231	21,747	6,461			28,208
1839	81,377	6,003	12,637			18,640
1840	882,620	39,687	15,296			54,983
1841	2,177,164	96,748	20,546			117,294
1842	14,552,357	523,428	16,789			540,217
1843	15,366,918	492,765	7,121			499,886
1844	18,420,407	595,238	10,018			605,256
1845	10,188,024	342,646	14,404			357,050
1846	16,823,766	614,518	10,278			624,796
1847	3,326,028	124,981	13,694			138,675
1848	1,994,704	84,278	7,739			92,017

Year.*	Manufactures of Lead. Pounds	Manufactures of Lead. Value.	Pewter and Lead. Value.	Bars, Shot, etc. Pounds	Bars, Shot, etc. Value.	Total Value.
1849	680,249	$30,198	$13,196			$43,394
1850	261,123	12,797	22,682			35,479
1851			16,426	229,448	$11,774	28,200
1852			18,469	747,930	32,725	51,194
1853			14,064	100,778	5,540	19,604
1854			16,478	404,247	26,874	43,352
1855			5,233	165,533	14,298	19,531
1856			5,628	310,029	27,512	33,140
1857			4,818	870,544	58,624	63,442
1858			27,327	900,607	48,119	75,446
1859			28,782	313,988	28,575	57,357
1860			56,081	903,468	50,446	106,527
1861			30,534	109,023	6,241	36,775
1862			28,832	79,231	7,334	36,166
1863			30,609	237,239	22,634	53,243
1864			30,411	223,752	18,718	49,129
1865			29,271	852,895	132,666	161,937
1866			44,483	25,278	2,323	46,806
1867			27,559	99,158	5,300	32,859
1868			37,111	438,040	34,218	71,329
1869			17,249			17,249
1870		28,315				28,315
1871		79,880				79,880
1872		48,132				48,132
1873		13,393				13,393
1874		302,044				302,044
1875		429,309				429,309
1876		102,726				102,726
1877		49,835				49,835
1878		314,904				314,904
1879		280,771				280,771
1880		49,899				49,899
1881		39,710				39,710
1882		178,779				178,779
1883		43,108				43,108
1884		135,156				135,156
1885		123,466				123,466
1886		136,666				136,666
1887		140,065				140,065
1888		194,216				194,216
1889		161,614				161,614
1890		181,030				181,030
1891		173,887				173,887
1892		154,375				154,375

*Fiscal years ending Sept 3 from 1790 to 1843 (1843 is for 9 months); from 1844 to 1886, ending June 30 (1886 is for 18 months); calendar years from 1887 forward.

IMPORTS OF ZINC INTO THE UNITED STATES SINCE 1867.*

Year.	Sheets, Blocks, Pigs, and Old. Quantity.	Sheets, Blocks, Pigs, and Old. Value.	Manufactures. Value.	Total Value.	Year.	Sheets, Blocks, Pigs, and Old. Quantity.	Sheets, Blocks, Pigs, and Old. Value.	Manufactures. Value.	Total Value.
	lbs.	$	$	$		lbs.	$	$	$
1867........	10,895,028	568,138	1,835	569,968	1880†........	10,448,681	515,678	a	575,678
1868........	12,885,416	621,156	1,623	622,779	1881........	8,187,993	328,212	a	328,212
1869........	21,518,298	1,068,978	2,083	1,071,061	1882........	30,320,128	1,240,117	a	1,240,117
1870........	18,763,808	925,357	21,696	947,053	1883........	8,695,898	319,890	7,5467	395,359
1871........	18,805,861	917,598	26,366	943,964	1884........	4,330,416	147,349	78,370	325,919
1872	22,507,191	1,116,409	58,668	1,175,077	1885	3,086,683	95,319	30,480	125,799
1873........	17,962,040	1,047,105	58,813	1,103,918	1886	4,791,521	150,101	48,278	198,379
1874.... ...	9,610,405	627,983	48,304	676,287	1887........	9,525,070	309,744	44,703	354,447
1875........	9,354,965	546,305	26,330	572,635	1888........	3,520,194	137,714	18,270	155,984
1876........	5,558,682	354,390	18,427	372,817	1889........	1,928,480	81,078	66,312	147,390
1877........	2,608,227	145,065	2,496	147,561	1890........	2,112,626	107,017	53,469	160,486
1878	2,526,804	127,134	4,892	132,026	1891........	814,218	41,369	18,424	59,793
1879........	2,531,016	106,344	3,374	109,718	1892	410,896	23,307	22,709	46,016
					1893	425,998	22,931	20,756	43,687

IMPORTS OF ZINC OXIDE INTO THE UNITED STATES.

Year.*	Dry.	In Oil.	Year.*	Dry.	In Oil.	Year.*	Dry.	In Oil.	Year.	Dry.	In Oil.
	Lbs.	Lbs.		Lbs.	Lbs.		Lbs.	Lbs.		Lbs.	Lbs.
1886...	2,526,389	79,788	1888...	1,401,342	51,985	1890...	2,631,458	102,298	1892...	....	....
1887...	4,961,080	123,216	1889...	2,686,861	66,240	1891...	2,839,351	128,140	1893...	....	....

TOTAL EXPORTS OF ZINC AND ZINC ORE FROM THE UNITED STATES SINCE 1864.*

Year.	Ore and Oxide. Quantity	Ore and Oxide. Value.	Plates, Sheets, Pigs, and Bars. Quantity	Plates, Sheets, Pigs, and Bars. Value.	Manufactures. Value.	Total Value.	Year.	Ore and Oxide. Quantity	Ore and Oxide. Value.	Plates, Sheets, Pigs, and Bars. Quantity	Plates, Sheets, Pigs, and Bars. Value.	Manufactures. Value.	* Total Value.
	lbs.	$	lbs.	$	$	$		lbs.	$	lbs.	$	$	$
1864	1,658,720	116,431	95,738	12,269	....	128,700	1879	1,195,920	40,399	2,132,949	170,654	....	211,053
1865	11,129,552	114,149	184,183	22,740	....	136,889	1880 †	618,128	18,388	1,737,776	154,817	....	174,205
1866	502,320	25,091	140,798	13,290	....	38,381	1881	2,130,240	16,437	1,382,853	116,941	....	133,378
1867	411,712	32,041	312,227	30,587	....	62,628	1882	710,750	14,487	1,159,949	823,384	....	837,871
1868	934,528	74,706	1,022,699	68,214	....	142,920	1883	235,200	9,292	125,594	8,616	....	17,908
1869	....	65,411	....	....	....	65,411	1884	813,120	22,867	136,804	10,606	3,097	36,570
1870	1,712,032	81,487	110,157	10,672	....	92,159	1885	697,080	20,297	171,577	11,638	9,704	41,639
1871	1,077,552	48,292	76,380	7,823	....	56,115	1886	2,981,440	49,455	917,229	75,192	13,526	138,173
1872	412,834	20,880	62,919	5,726	....	26,606	1887	526,400	17,286	136,690	9,017	16,789	43,092
1873	26,208	2,304	73,953	4,656	....	6,960	1888	510,720	18,034	62,234	4,270	19,098	41,402
1874	285,600	20,037	43,566	3,612	....	23,649	1889	2,997,120	73,802	879,785	44,049	35,732	153,543
1875	345,296	20,659	38,000	4,245	1,000	25,904	1890	8,664,320	195,113	3,925,584	126,291	23,587	344,991
1876	1,139,936	66,259	134,542	11,651	4,333	82,243	1891	13,071,840	149,435	4,294,656	278,182	38,921	466,538
1877	719,936	34,468	1,419,922	115,122	1,118	150,708	1892	2,058,560	41,186	12,494,335	669,549	161,794	877,529
1878	1,797,600	83,831	2,545,320	216,580	567	300,978	1893	109,760	1,271	7,278,874	403,590	248,382	653,243

(*a*) Not stated.

*** Fiscal years ending June 30 until 1883 ; calendar years subsequently.**

† From 1880 on the figures are taken from the summary statement of imports and exports published by the Bureau of Statistics, United States Treasury Department.

PRICES.

The prices of the metals vary from time to time with other commodities. With a view to completeness, we have brought together in the following tables figures of prices, both of metals and ores, for recent years. The prices for the United States were taken from the Mineral Industry. Those for Great Britain have been compiled from different sources, specifically referred to in connection with the tables. The prices of ores and metals in Europe were calculated from tables given by Messrs. Fuchs and DeLaunay [*91, vol. ii, pp. 468-69*]. All prices of ores are given in dollars per short ton, and of metals in cents per pound—the value of the English pound sterling being taken at $4.86, and of the franc at $0.193.

AVERAGE YEARLY PRICES OF LEAD IN NEW YORK.

In cents per pound.

1870	6 25	1876	6.13	1882	4 91	1888	4 42
1871	6 08	1877	5 49	1883	4 32	1889	3 93
1872	6 30	1878	3 61	1884	3 74	1890	4 48
1873	6 32	1879	4 14	1885	3.95	1891	4 35
1874	6.01	1880	5 04	1886	4 63	1892	4 09
1875	5.85	1881	4 81	1887	4 50	1893	3.73

AVERAGE YEARLY PRICES OF SPELTER IN NEW YORK.

In cents per pound.

1875	7.00	1880	5 51	1885	4 35	1890	5 55
1876	7 25	1881	5 24	1886	4 40	1891	5 02
1877	6.03	1882	5.33	1887	4.63	1892	4 63
1878	4 88	1883	4.50	1888	4.91	1893	4 08
1879	5 04	1884	4.44	1889	5 02		

PRICES OF LEAD ORE IN GREAT BRITAIN.

In dollars per short ton.

1872	$59 14	1877	$60.46	1882	$44 10	1887	$36.22
1873	66.64	1878	45.88	1883	37 10	1888	37.10
1874	63 66	1879	44 62	1884	32 28	1889	38.68
1875	67 04	1880	49 00	1885	34 65	1890	38.68
1876	63.66	1881	44 00	1886	38 50	1891	35 35

From 1872 to 1882, inclusive, the prices are taken from Hunt [*116*]; for 1883 to 1891, from Fuchs and DeLaunay [*91*].

PRICES OF LEAD IN LONDON.

In cents per pound.

1771	2 91	1803	6.02	1840	3.94	1870	4.05*
1772	2.69	1804	6.08	1841	4.37	1871	3.95
1773	2 64	1805	6 00	1844	3.68	1872	4.34
1775	2.84	1806	7.76	1846	4.11	1873	5.06
1776	2.80	1807	6.54	1849	3.45	1874	4.80
1777	2 80	1808	6.51	1850	3.80	1875	4.88
1778	2.69	1809	6 77	1851	3.72	1876	4.70*
1779	2.50	1812	5 02	1852	3 88	1877	4.46*
1780	3.42	1813	5.59	1853	5.07	1878	3.63*
1781	3 21	1814	5.81	1854	5.14	1879	3.22
1782	3 57	1816	3.53	1855	5.01	1880	3.56
1783	3 50	1818	5.95	1856	5.21	1881	3 25*
1784	3.50	1820	4 67	1857	5.17	1882	3.13*
1785	3 29	1821	4.89	1858	4.67	1883	2.81*
1786	4.67	1823	4 83	1860	4.83	1884	2 59
1790	3 50	1824	4 56	1861	4.78*	1885	2.51
1792	4 22	1825	5.48	1862	4.52	1886	2.87
1793	4 15	1826	4 13	1863	4.52	1887	2.80
1794	3.15	1828	3.42	1864	4.69	1888	3.02
1796	4.01	1830	2 64	1865	4.37	1889	2.84
1798	3.37	1832	2.53	1866	4.45	1890	2.91
1799	3 88	1835	3.69	1867	4.25*	1891	2.70
1800	4.56	1836	5 45	1868	4.20*	1892	2.34
1801	5 21	1837	4.72	1869	4.25*	1893	2.07*

These prices have been calculated by Mr. John N. Judson, from a table given in the "Statistiche Zusammenstellungen uber Blei, Kupfer, Zink und Zinn von der Metallsgesellschaft, Frankfort-am-Main."

Those figures marked with an *, with the exception of the figures for 1861 and 1893, are taken from the Mineral Resources of the United States for 1885.

As specie payments were suspended in Great Britain from 1797 to about 1844, the prices quoted between these dates were in bank paper, gold standing at a premium.

PRICES OF ZINC AND ZINC ORE IN GREAT BRITAIN.

YEAR.	ORE. Dollars per ton.	METAL. Cents per lb.	YEAR.	ORE. Dollars per ton.	METAL. Cents per lb.
1858	....	5.59	1870	$15.18	4.14
1859	$13.20	4 62	1871	14.30	4.09
1860	11.00	4.51	1872	13.60	5 01
1861	8.80	3.94	1873	14.30	5 09
1862	9.35	4.03	1874	14 85	5.13
1863	10.34	3 98	1875	18.10	5 45
1864	13.31	4.87	1876	20.24	5.31
1865	12.76	4.53	1877	17.01	4.79
1866	14.69	4.82	1878	14.09	4.29
1867	13.49	4 63	1879	15.24	3.91
1868	13.49	4 47	1880	17 82	4 23
1869	13.97	4.52	1881	14.67	4 72

NOTE.—This table is calculated from figures given by Hunt (*116*).

PRICES OF LEAD ORE AND METALLIC LEAD IN EUROPE.*

(Prices of ore in dollars per short ton, and of metal in cents per pound.)

	Austria.		Belgium.		France.		Italy.		Prussia.		Saxony.		Bavaria		Other German Countries		Spain.	
	Ore.	Metal	Ore.	Metal.	Ore.	Metal.	Ore.	Metal	Ore.	Metal.	Ore.	Metal.	Ore.	Metal	Ore.	Metal.	Ore.	Metal.
	Dolls.	*Cts*	*Dolls.*	*Cts.*	*Dolls.*	*Cts.*	*Dolls.*	*Cts.*	*Dolls.*	*Cts.*	*Dolls.*	*Cts*	*Dolls.*	*Cts*	*Dolls.*	*Cts.*	*Dolls.*	*Cts.*
1880 ...	....	......	28 70	3.36	40 43	3 25	42 35	......	....	....	34 13	......	19 25	.....	40 08	......	15 23	2.14
1881 ..	33 25	3.70	30 80	3 04	38 50	3 21	....	....	26 79	....	36 23	3.04	......	.....	38 68	2.76	23 80	2.91
1882	34 30	3 66	24 98	2 98	42 35	2.84	30 98	3 24	26 60	2 92	32 90	2 92	25 20	....	37 11	2 88	23 98	2 71
1883	31 85	3 29	31 45	2 64	44 45	2 49	....	.....	24 67	2.59	25 38	2 74	25 20	.....	37 11	2 63	22 40	2 61
1884 ..	28 53	3 10	25 03	2 33	41 48	2 32	26 60	2 63	22 58	2 29	38 68	2.38	14 52	......	31 50	2 26	20 13	2 53
1885 ..	30 27	3.21	25 20	2 31	40 95	2.29	24 50	2 62	22 23	2.25	51 80	2 85	15 05	......	35 00	2 45	20 65	2 55
1886 ..	33 25	3.24	26 30	2.71	36 40	2 64	31 15	2.89	23 63	2.59	......	......	16 98	....	......	......	22 75	2 36
1887 ..	33 60	3 34	29 40	2 78	39 03	2 63	32 08	2.70	23 63	2 85	34 48	2 89	....	......	......	2 63	24 15	2 28
1888 ..	39 38	3 61	19 25	2 88	37 63	2.70	34 46	2.95	24 15	2.84	29 57	2 95	14 52	......	....	....	21 70	3 00
1889 ..	38 33	3.64	17 50	2.72	38 33	2 65	33 43	2 98	24 50	2 83	29 57	2 87	16 45	....	23 27	....	....	....
1890 ..	36 93	3 58	18 55	2 85	35 31	2 96	....	.....	25 20	2 70	....	.....	......	....	......	....	....	......
1891 ..	34 48	3 41	20 13	2.68	32 02	2 76	37 11	......	24 50	2.60	31 85	2.85	16 45	....	28 70	....	14 18	....

* These prices are recalculated from tables given by Fuchs and DeLaunay [*91*].

PRICES OF ZINC ORES AND METALLIC ZINC IN EUROPE.*

(Prices of ore in dollars per ton, and of metal in cents per pound.)

	Austria.		Belgium.		France.		Italy.		Prussia.		Saxony.		Other German Countries.		Spain.	
	Ore.	Metal.	Ore.	Metal.	Ore.	Metal.	Ore.	Metal	Ore.	Metal.	Ore.	Metal.	Ore.	Metal.	Ore.	Metal.
	Dolls.	*Cts.*	*Dolls.*	*Cts.*	*Dolls.*	*Cts.*	*Dolls.*	*Cts.*	*Dolls.*	*Cts.*	*Dolls.*	*Cts*	*Dolls.*	*Cts.*	*Dolls.*	*Cts.*
1880	4 90	......	10 15	3.79	5 60	3 91	10 15	......	....	....	....	......	4 20	......	5.43	3.69
1881	....	3.76	8 92	3 34	5 30	3 51	....	....	3 15	....	....	3.24	12 25	......	6 48	3.64
1882	5 78	3.55	6 13	3.39	5 95	3.50	8 75	......	3 68	3.41	....	3 61	8 23	......	5 95	3.65
1883	6 48	3.50	6 30	3.28	6 04	3.41	....	......	2 80	3.11	....	3.12	8 58	....	4 55	3.73
1884	5 43	3.38	6 48	3.01	5 43	3.42	10 50	......	2 63	2.98	....	3 06	8 58	......	4 55	4.93
1885	4 55	2.99	6 65	3.66	10 50	3.33	10 84	......	2 45	2.89	....	2.82	5 25	......	4 55	4.64
1886	3 85	3.56	7 00	2 98	10 50	3.29	11 23	......	2 28	2.84	....	....	5 60	......	5 08	4.84
1887	4 20	4.36	7 33	2.63	9 10	3 28	11 78	......	2 45	3.08	....	3.06	....	......	4 38	5 63
1888	5 78	4 70	8 05	3.75	11 69	3 55	14 35	......	4 32	3 53	....	3 69	4 20	......	4 55	5.63
1889	6 13	4.90	10 67	4.11	17 50	4 11	14 53	......	5 43	3 90	....	....	5 43	......	....	....
1890	7 35	5.77	14 00	4 88	17 50	4 46	....	......	6 65	4.82	....	....	....	....	....	....

* These prices are recalculated from tables given by Fuchs and DeLaunay [91].

PART II.

Lead and Zinc in Missouri.

A report on the history of mining in the State, on the geology of the mining districts and ore deposits, and on the lead and zinc industry.

LEAD AND ZINC MINING DISTRICTS OF MISSOURI.

CHAPTER VII.

HISTORY OF MINING IN MISSOURI.

PREVIOUS TO THE YEAR 1800.—1800 TO 1820.—1820 TO 1830.—1830 TO 1850.—1850 TO 1860.—1860 TO 1870. 1870 TO 1880.—1880 TO 1893.

The lead and zinc ores of Missouri are confined to the southern part of the state—not a single workable deposit, to the writer's knowledge, having been developed north of the Missouri river. In this southern part, three districts are recognized. These are:

1) A Southwestern District, occupying the extreme southwestern counties;

2) A Southeastern District, occupying the eastern counties;

3) A Central District, occupying the central northern counties.

The location and limits of these districts, as defined by this report, are shown on the accompanying geological maps. Though other deposits and mines exist outside of the defined limits of these districts, this separation is a useful and a natural one, as the deposits of each district have certain distinctive characteristics. The classification is, hence, retained in the following report, and the discussions of this and succeeding chapters will be regulated by it. The history of the first one hundred and fifty years of lead mining in the state deals almost exclusively with the Southeastern district.

PREVIOUS TO THE YEAR 1800.

Lead ores were discovered and worked in the eastern states before those of this western country were known. Missouri may, however, lay claim to being the scene of the first lead mining in the Mississippi valley. It is also probable that the first discovery of such ores by the white man was made here. It is true, that lead ores are thought to have been discovered in the Wisconsin lead region, by Nicolas Perrot, about 1682 [*121, p. 498*], and to have been smelted by the Indians in 1690 [*177, p. 82*]; but this report is of doubtful authenticity. The first discovery of lead in Missouri, according to reliable information, was by

Penicaut, one of LeSueur's party, which ascended the Mississippi in the year 1700. He refers to a mine reached by the Meramec, about 50 leagues west of the Mississippi river, and west of Ste. Genevieve, whence the Indians got their supply of lead. As this same expedition continued up the river and discovered lead ore near the southern boundary of Wisconsin, in August of the same year, Missouri cannot lay claim to great priority in the date of discovery.

When one considers the imperfect means of communication of those early days, the wild and unexplored condition of the country, the dangers that were known to surround early settlers, and the vast distances which separated them from friends and civilization, it is remarkable how soon occupation and possession followed upon exploration and discovery. The present case is no exception to that rule. Hardly more than a decade after the first discovery, the Crozat patents were issued by Louis XIV, in 1712, with special privileges applying to the discovery and operation of mines in the then territory of Louisiana. Though little or nothing was done in the direction of mining under the privileges of this patent, immediately upon its transfer to the "Company of the West" or the "Mississippi Company," in 1717, active operations were prepared for under the promoting genius of John Law.

The fabulous and fictitious accounts growing out of the early explorations had given rise to exaggerated ideas of the mineral wealth of the country, especially of the prevalence of the precious metals. Such ideas were doubtless stimulated by the agents of the company, and many inducements were held out to miners and mechanics to emigrate. About the first effort made in the direction of mining, was by Sieur De Lochon, in 1719, on the Meramec. He was sent out by the Mississippi company, and made some ineffectual attempts to smelt the lead ore, but, being in search of silver, he did not accomplish much, and soon abandoned the field. As Charlevoix says [*37, p. 23*]:

"He dug in a place that was showed him, took up a pretty large quantity of the mineral, a pound of which, that took up four days to melt, produced as they say, two drachms of silver; but some persons suspect that he put in the silver." A few months later he tried for lead, "and from two or three thousand weight of the mineral he extracted fourteen pounds of very bad lead, which cost him 1400 livres."

A few other attempts were also made at this time, but proved equally abortive.

In this same year, 1719, according to Schoolcraft [*203, p. 19*], Philip Francis Renault, son of an iron founder, was made Director-General of the mines of the Company of the West, and left France for Louisiana with 200 artisans and miners. With him, it is stated, came LaMotte, a man reputed to have been versed in mineralogy. The expedition took on at St. Domingo 500 slaves for working the mines, and can thus be credited with the introduction of slavery into the colonies. Renault established himself near Kaskaskia in 1720, and sent out his exploring parties from there, mainly in search of, and with the hope of finding precious metals. In one of these expeditions, the deposits of Mine La Motte, in Madison county, were discovered, and, being subsequently worked to a small extent under LaMotte, they acquired his name.* Old Mine and Mine Renault, both in Washington county, respectively six miles N. and 8 miles N. W. of Potosi, were discovered soon after,† between the years 1724 and '26, and mining of the ores was started at a number of places. Schoolcraft, in 1818, remarks as evidence of the early industry, the existence of a great number of old diggings scattered over the country. At the same time, apparently, Renault also instituted, with reasonable success, the smelting of the ore on a large scale. The product was sent to France via New Orleans.

It is probable that a permanent and flourishing industry would have been built up here at this early date, had it not been for the failure of the whole gigantic enterprise piloted by Law. The collapse of the bank established by his company, which is credited with having had in circulation over 200 million dollars in worthless notes, brought about a cession of the charter of tho company to the Crown in 1731.

Though thus deprived of almost all means of support, Renault remained courageously in the country for nearly ten years after the dissolution of the company. Grants covering Mine La Motte and other tracts, which, we may incidentally note, were the first land grants made in Missouri, had been conveyed to him as early as 1723. Their possession, doubtless, simulated him to continued exertions toward

* As opposed to this account of the discovery of Mine La Motte. Du Pratz, in his history of Lousiana, states that La Motte resigned as Governor in March 1719, and returned to France, where he died the next year. It is further stated that in 1713, M. de la Motte Cadillac, or La Mothe Cadillac, arrived in Louisiana with a commission as Governor. According to one account he conducted, in the year 1715, an expedition for the search of silver mines into the country of the Illinois [*177, pp. 89-91*], and returned with fine specimens of lead ore. It is supposed that Mine La Motte was discovered on this expedition.

† The locations of these and of other historic mines of note, are shown on the Southeastern district map.

the development of the country. In 1742, however, apparently losing courage, he abandoned his work and returned to his native country, thus bringing to a close the first period of mining in Missouri.

During the next 60 years, or up to the end of the 18th century, only desultory mining was practiced. From Austin's [*4, p. 188*] account it appears that, between the time of Renault's departure and the cession of Louisiana to Spain in 1762, mining was feebly prosecuted by the French at Mine La Motte, Old Mines and at Mine a Gerbore, which last is situated 18 miles north of Mine La Motte, in St. Francois county, all of which deposits had been discovered during Renault's time. Probably some little work was prosecuted at other diggings, but others, such as Mine Renault, remained inactive during this period and for many years after.

In 1763, according to Austin, the Mine a Burton was discovered at what is now the town of Potosi, in Washington county. The discovery was made by Francis Burton, a Frenchman, while on a hunting expedition.* Work was apparently started here at once, and the prospects and ease of mining were such that people were drawn from all the other mines, which were consequently abandoned for a time. This was especially the case with Mine La Motte, where the disseminated ores were found difficult to work and smelt, and were consequently not rated high. About the same time, the Mine a Robina, two miles southeast of Potosi, was discovered.

These discoveries stimulated mining to a certain extent, but, aside from this, during the next 30 years of Spanish control the industry was languidly pursued. The Mine a Burton and others of the vicinity were principally worked, and during the latter years of this period Mine La Motte, Old Mine and Mine Renault also supplied much ore. According to Col. A. W. Maupin, of Union, the Thomas mine, of Franklin county, was included in a Spanish grant and was worked in this period.

During the last five years of the 18th century, mining received a decided stimulus. New deposits were discovered, the scale of mining was enlarged and the methods of smelting improved. Among other mines opened at this time were the Mines a Lanye, about 16 miles SSE. of Potosi (probably in St. Francois county), discovered in 1795 by a man of the same name. Others were the Mine a Maneto, or Amer-

* Burton was still living near Ste. Genevieve in 1818, and was then estimated to be 106 years old. His life had been one of most varied experiences and vicissitudes. About 20 years before his death he obtained a grant of four acres at the mine, as compensation for his discovery.

ican mines, on Big river, in St. Francois county, about 12 miles southeast of Potosi, discovered by an American in 1799; and Mine a La Platte, near the southeastern corner of Washington county, about two miles from Big river, discovared in 1799, and operated to a small extent.

A noteworthy event in the history of southeastern lead mining was the arrival of Moses Austin in 1799. He had formerly operated the lead mines of Wytheville, Virginia, and brought many ideas and improvements which were new to the western country. He obtained a grant of one league square at Potosi, in consideration of which he was to erect a furnace and other works. This he did in the following year. Up to this time, ore had been dug from the clay in shallow pits, seldom over 10 feet deep. Austin sank the first regular shaft, and penetrated the rock to a depth of 80 feet. The smelting at this period was also very crude and wasteful in its methods. It was done either on log heaps or in a rude furnace constructed like a lime-kiln. The process often yielded only about 35% of metal; the ashes of lead or litharge were entirely wasted. At the time of Austin's arrival, about 20 such furnaces were in operation near Potosi. He erected the first reverberatory or ash furnace, and, by 1802, had apparently captured the whole smelting business of the neighborhood, as only one of the old furnaces was then running. He also erected a shot-tower in 1799, and works for the manufacture of sheet lead. From these the arsenals of New Orleans and Havana were supplied.

The introduction of these improvements enhanced the value of the mines. About the same time, some American families immigrated into the territory, and a little later, with the cession of the country to the United States, the influx of the Americans became very large. The total production up to the end of the century is estimated to have been in the vicinity of 18,000 tons of lead.

1800 TO 1820.

As a result of this increase of population, the first 20 years of the century was a period of almost continuous growth and development in the lead-mining industry, and the average rate of production increased to about 1,100 tons of lead per year.

Among the important discoveries of this period, may be cited the Mine a Joe, later called the Bogy mine, in St. Francois county, on Big river, near the site of the recently erected Desloge concentrating works. This mine was discovered in 1801 by Americans, Baker and

Ally. It was taken from them by the authorities in 1802. During the first year of its discovery, a large amount of lead ore was mined, but, after it was seized, little ore was produced during the immediately following years. Indeed, Austin, writing in 1804, supposed the deposit not to be very extensive.

Soon after this, in the year 1803, several new discoveries were made in Washington county, including the Mine a Martin, 4½ miles east of Potosi. In 1806, New Diggings, a few miles S. E. of Potosi, were discovered, and produced for a few years at the rate of about 1000 tons of ore per annum.

In St. Francois county, the mines at Hazel Run were first opened in 1806. They are situated about five miles northeast of Bonne Terre. From Bryan's mines, which are located here, Schoolcraft states that nearly 500 tons of lead were made in the first year of their discovery.

The Shibboleth mine was discovered in 1811. It is in Washington county, less than a mile northwest of the present town of Cadet. This was one of the most productive mines of that period, and is credited in the first year of its operations with having yielded 2500 tons of ore, equivalent to 1563 tons of lead. In subsequent years its production declined somewhat.

In 1814, the Fourche a Courtois mines were discovered. They are located in the S. W. corner of Washington county, in townships 36 N, 1 E and 1 W, around the present postoffice of Palmer. The mines at Richwoods, in the N. E. corner of Washington county, including the old Lebaume mines and French diggings, were also discovered near this date.

Gray's mine, in Jefferson county, between one and two miles south of Frumet, seems also to have been discovered about this time, as does also McKane's mine on Dry Creek, near the mouth of Big river.

In addition to these new discoveries, the older mines by no means ceased operations. Thus, Mine a Burton was worked continuously, during the mining season at least, employing in the neighborhood of 200 men in some years. The period of maximum production was between the years 1804 and 1808; but during the 21 years, 1798 to 1819, the output is stated by Austin and Schoolcraft to have been 5430 tons of lead. In 1818, the mine was in a state of decline, and not over 30 miners were employed.

Mine La Motte was also a constant and large producer. About 1803, Austin estimated the annual production of lead to be about 100 tons, by 30 men, employed from four to six months in the year. He states further that this was a great reduction from the rate of preceding years, due to the fact that the mine was then claimed as private property, and the residents were not allowed to work the ores, as was the case during the preceding century, when the mine was considered public property. Work was apparently actively resumed later, however; for, in 1819, we find Schoolcraft estimating for the immediately preceding years an annual production of 400 tons of lead, and Mills [*147, p. 46*] has allowed as a total for the years 1804 to 1819, 4000 tons of lead, or 250 tons per year.

The mines thus far cited were the scenes of the principal operations during these early years of American possession. Other mines were, however, producing considerable quantities. Among these were the Old mines, employing in 1804 about 30 hands, Grays and Doggett's mine at Hazel Run, and McKane's mine in Jefferson county. In all, Schoolcraft cites 45 mines worthy of note, in Jefferson, Washington, St. Francois (then part of Ste. Genevieve, Washington and Jefferson counties) and Madison counties, which had been worked or were working in 1819. Of these, 39 were in Washington county, 3 in Ste. Genevieve county, 2 in Jefferson and 1 in Madison county as then defined; 27 were in operation in 1819, giving employment to 1130 men for greater or less portions of their time. The most extensive were Mine a Burton, Mine Shibboleth, Le Beaume's, Old Mines, Bryan's mines, Mine a Robino, Mine La Motte, Mine a Joe, Mine Renault and New Diggings, all of which we have before referred to. Further, with these are to be classed Pratt's, near Big river, about 16 miles E. of Potosi, at the town of Bonne Terre, in St. Francois county, recently known as Desloge mine and now part of the St. Joe Lead company's property; Mine a Straddle, in Washington county, about 10 miles W. of N. of Potosi, near the old Renault mine; Mine Liberty, about a mile SE. of Mine a Straddle; Cannon's mine, about 2 miles E. of Old Mines, in Washington county; and Mine Silvers, some 8 miles W. of Potosi, between it and the Palmer mines.

Outside of this southeastern district, little or no mining seems to have been done. Schoolcraft [*203, pp. 60-61*] refers in 1819 to discov-

eries of lead ore on Otter creek in Washington county, on Strawberry river in Lawrence county, on White river, on the James river, on the Meramec, Gasconade, Osage, and "Mine" rivers. He states that only small diggings had been made there, and that no ore was smelted, though remains of ancient works had been found on White river.

Brackenridge, writing in 1810, says that he has been informed by hunters of the existence of lead ore in great abundance on the Osage river and in the country drained by White river [*28, p. 146*]; and Schoolcraft again in 1818 found lead ore in Stone county, and smelted it for bullets [*204*].

The presence of zinc ore had been recognized as early as 1810 by Bradbury, at Mine a Burton, and its [*28, p. 67*] occurrence is noted by Schoolcraft at the Renault, Elliot, Brushy Run and New Diggings mines, all in Washington county. With his characteristic acumen, the latter predicts the future value of this ore. It is interesting further to note that the terms "tiff," as applied to barite, and "glass tiff," as applied to calcite, were used as far back as 1810.

The methods of smelting the ore, though in places improved over those of the preceding century, had generally advanced but little since Austin had inaugurated the use of the ash furnace. The old log furnace continued in common use. The yield from the log furnace was generally about 50%, and from the ash furnace about 15% more—making the total product of lead 65% of the ore, obtained at the cost of excessive amounts of fuel and labor. The furnaces were generally built of limestone, which burnt out quickly and had to be frequently rebuilt. Schoolcraft condemns the current practice strongly, and characterizes the furnaces as "defective in the plan, constructed of improper materials, and the workmanship is of the rudest kind." He recommends the use of blast furnaces.

All the lead manufactured was hauled in wagons to Ste. Genevieve and to Herculaneum. Ste. Genevieve was, during the early years, the only large shipping point: but, with the establishment of Herculaneum, about half of the product went there. At this latter point, there were 3 shot-towers in 1818, erected on the river bluffs, where shot was made by letting it fall down the banks. From these points, the lead was shipped to Philadelphia, New York and New Orleans. The total amount of pig and bar lead and shot sent out during these years, Schoolcraft estimates, in 1819, to have been about 1500 tons per year.

The work at the mines and furnaces, though employing a large number* of men, was of an intermittent character, the ore being taken out by the white residents, or by the slaves of the wealthier men, during such times as there was little or no work on the farms. This aggregated about 3 or 4 months in the year. The nature of the work was also desultory and on a small scale. The only tools used in 1811 appear to have been a pick, a wooden shovel and a sledge-hammer to break the rock. In 1819, however, Schoolcraft refers to the drill being used for blasting. Though Austin ventured a shaft 80 ft. deep, no others were sunk to a greater depth during this first score of years of the century, and not a single engine for hoisting or pumping had been introduced. In the majority of cases, the depth of the excavation was limited to the distance at which rock was struck, the material being first thrown out by hand and shovel to a depth of perhaps 15 ft., and then lifted out by bucket and windlass. The miners generally segregated about various centers until the surface ores were exhausted, or until some rich find at another locality caused them to swarm to that neighborhood.

Though the undeveloped condition of the country was to a great extent the cause of these primitive methods of working, the system of land tenure also contributed to that end, as was recognized and protested against by Austin [*1, vol. iii, pp. 609–613*] and others during these early years.

Under the Spanish rule, four acres of land had been "granted" to all discoverers, and elsewhere on public lands all were allowed to work free from any tax. At first, under the American regime, little attention was paid to the mining rights, and a chaotic condition arose as to the possession of titles of lead lands. To remedy this, Congress passed a law, in 1807, reserving all lead lands, salt springs, etc., and authorizing the Governor of the territory to grant three-year leases to discoverers, who were also required to pay a certain royalty. The reservations were made from reports of the Land office surveyers, and, as these traversed only certain lines, the results were necessarily imperfect. The duty of leasing was attached to the office of Recorder of Land Titles at St. Louis. The rent charged was generally one-tenth of the ore raised. In 1811, 300 acres of land were thus leased near the Old Mines for a period of 12 months; in 1814 Mine a Straddle and six other

* In 1811 Brackenridge allows 350 hands employed in the mines alone, while in 1819 Schoolcraft places the number at 1130, including blacksmiths, teamsters, smelters, etc.

mines, covering in all 3300 acres, were leased to Amable Partenay. The periods of the leases varied from 12 months to 2 years, and the rents were variously, \$3, \$3½ and \$4 per 1000 lbs. [*1, vol. iv, pp. 526, 555*].

There was very little return from this system, as few would trouble to take out a lease, since there was no special agent to enforce its conditions, and to protect the lessee. Moreover, the maximum length of term of 3 years was so short that a mine could not be well opened during that period, and no individual or company would expend large sums in sinking shafts or making other improvements when there was a chance that, after the end of three years, the product of these labors would fall into the hands of another. Rules were gradually established by custom which were more regarded. According to these a person was allowed to claim the ground for 25 ft. in every direction from the point at which his discovery was made, while others were allowed 12 ft. square in which to sink pits over the adjacent ground. This they were allowed to hold until they abandoned the work.

The price of lead at the mines during this period was about 4 cents a pound, and the digger received about 2 cents and worked independently. The cost of transmitting 1000 pounds to Philadelphia in 1816 was estimated by J. R. Jones [*1, vol. iii, p. 605*] as aggregating \$83.15. Inasmuch as the price of lead in 1819 was only 6 cents in Philadelphia, and 5½ cents in New Orleans, while the price of 4 cents at the mines remained the same, it would seem that Mr. Jones' estimate must be excessive.

1820 TO 1830.

The data relating to the lead mining of the next 10 years are not very abundant; but, from the best we can gather, it appears that the industry hardly more than maintained the rate of production of the preceding years. Notwithstanding the fact that Schoolcraft, in the report already cited, had written quite glowingly of its prospects, had recommended a number of important improvements, and had ventured a prediction that larger quantities of ore were yet to be found at depths, the same systems of mining and smelting continued for a number of years; no deep shafts were sunk or large operations undertaken. A great number of new discoveries were made, it is true, and some of these were of importance; but, as the extraction of ore was principally from shallow diggings, the newly opened deposits were soon

exhausted of their surface ores. Hence, the production did not increase very much, despite the number of new openings, until the last half of the decade, when a strong advance is noticeable. This was doubtless largely due to the fact that, in 1824, the import duty on lead was raised from 1 ct. to 2 cts., which, together with the increase of the demand for lead in Europe, caused in Missouri a rise in the price from 4 to 6½ cts.; in 1825 it had fallen again to 5½ cts.

In 1820, deposits of lead ore were found in southern Cole county. In 1824, the Sandy mines [*32, p. 681*], in Jefferson county, were discovered, about 5 miles NE. of Hillsborough, and soon became large producers. In the same year the well-known Valle mine deposits were discovered by Joseph Schutz [*216, pt. ii, p. 33*]. It is located about 7 miles NE. of Bonne Terre, in St. Francois county, near the line of Jefferson county. This mine produced in the first 5 years of its operations about 1000 tons of lead. Bisch's mine, in the same neighborhood, at the present Silver Springs station, was discovered about 1825, and soon produced at the rate of 100 tons of lead per year. The Perry mines, adjoining, were discovered a little later.

About this time, excavations were also made on Plattin creek, in Jefferson county, at the site of the McCormick mines, a little south of the present postoffice of Plattin [*33, p. 310*]. In Perry county, the Wilkinson diggings were opened in 1827, by Wilkinson, Brown and Pratte, and were worked up to the latter part of 1828, and then abandoned, having produced about 20 tons of ore. The Nashville mines, in Jefferson county, close to Frumet, were opened in 1827, and yielded small amounts of ore. It is interesting in passing also to note the extension of mining into Franklin county at this time, where, according to Litton [*216, pt. ii, p. 27*], a small amount of ore was dug and smelted in the years 1827 to '28, on the School lands, in township 42 N., 1 W.

Along with the operations of these newly discovered deposits, the old and longer opened mines also continued work. In 1823, agents George Bullitt and T. Quarles, in their report to the Commissioner of the Government Land office, describe briefly the mines at that time operating, and include a notice of the nature of the deposits and of the methods of working and smelting the ores [*1, vol. iii, p. [illegible]*]. Mine La Motte, they write of as in operation and supplying 5 furnaces. At the time of writing, 50 hands were employed and the production for the preceding 3 years had been about [illegible] tons of lead.

In this report, we find also a description of the Flat river mines, which are divided into five groups of diggings. The mines of the first group are termed the Flat mines, on Flat river, 2½ miles above its mouth, and consequently represented by the old diggings now found east of the present Taylor shaft and below Flat river station. These are described as having been very profitable, but, at the time, were employing only about 15 men. In the second group is Mine a Joe, already referred to and located. The ore is described as occurring in veins between rocks, separated from 5 to 30 feet, with N.–S. courses. Large quantities of ore had been raised here, but "rock water" was encountered at depths of from 20 to 30 ft., and interfered with the extension of the work. Only four hands were employed there at the time. The third group is at the Gumbo mines, about half a mile N.W. of Mine a Joe. These were worked a little from 1820 to '21, but were abandoned in 1823 and thought to be exhausted. The fourth group of diggings was called the Yankee diggings, discovered a few years back. They had been very productive. They were located about 2 miles NW. of the Gumbo mines. Twenty-eight "intruders," or miners without lease, were working there at the time. The improvements of these mines were considered the best of any on Flat river, but they consisted merely of a few huts for the miners to live in. The last group of Flat river diggings was the McKee mines, in the same neighborhood, but they are not specially described. The total production of these mines for 1823 is estimated to have been 200 tons of lead, and the number of men employed is placed between 50 and 1000. A description is given of the location of the mines and of the surrounding country, and reference is made to the good roads connecting the works with Ste. Genevieve and Herculaneum. Other mines operating at that time are mentioned, including Mine a Burton, Robino, Courtois, New Diggings, Valle and La Clare. The last are described as in township 36 N., 3 E., near the dividing line between it and township 37 N., and consequently in Washington county, a few miles S.W. of the present town of Hopewell. The production of all these mines described in this report in 1823 was between 400 and 450 tons of lead, and they gave employment to between 150 and 275 men. The total amount produced in Washington and St. Francois counties for 1823, is placed at 2500 tons of lead.

In 1823, the mines at Hazel Run ceased work, and very little was done there for many years afterward.

Some progress seems to have been made in the smelting of ores during this period. In Bullett's and Quarles' report, above cited, the yield of lead from some furnaces is stated to have been as much as 70%, though the general yield of the ores was estimated at about 60%. Lieutenant Thomas [*1, vol. iv, p. 557*], however, writing in 1825, characterizes the methods as wasteful, consuming large quantities of fuel, and as yielding on an average only about 62%. The same old log furnaces were used, and were most poorly constructed. The smelters paid the miners 800 pounds of lead for each ton of ore delivered. The cost of smelting at this time, as estimated in Thomas' report, was about $4.00 per ton of ore, so that the smelters made a profit of about $11.00 on each ton. On the other hand, the miners made at times as much as $15.00 per day, though Schoolcraft states $2.25 a day is a fair average of the amount a miner could make throughout the year. Thomas allowed only $1.00 a day on an average.

About 1827, according to Broadhead [*32 pp. 13 and 330*], the first furnace was erected in Cole county, near Pratt's mill, by Mr. Chouteau of St. Louis. In 1828, Mr. George Crosswell began smelting at Fourche a Renault, about a mile north of the postoffice of that name [*216, pt. ii, p. 60*].

The manufacture of lead also continued, and shot-towers were in operation at Herculaneum and at other points on the Mississippi bluffs. The lead was still hauled in carts and wagons to Ste. Genevieve, Herculaneum, and, during the last half of the period, to Selma also. The length of these hauls was great, and the traffic so heavy that the roads got into a very bad condition — such, that Lieutenant Thomas urged the construction by the government of a road from Potosi to the Mississippi river.

The total number of people employed during this decade is difficult to estimate. In the years 1824–25, Thomas places the number, all told, at 2000 employed half their time, part being given to farming. These were largely negro slaves. He also states that the number of mines had more than doubled since 1816, and was growing daily.

The method of working the mines remained essentially the same. This is attributed by Thomas to three principal causes: 1) the absence of capital and skilled labor; 2) the scarcity of labor; 3) the ease with which ore could be obtained near the surface.

Up to the year 1824, the same looseness, regarding the leasing and control of lead land, that had prevailed in the past, continued. In that

year, Lieut. Martin Thomas, above referred to, was appointed U. S. Superintendent of mines for Missouri and the West generally, with authority to report land for reservation, to enforce the conditions of the lease, and to protect the lessee. He appears to have entered energetically upon the discharge of his duties. Up to this time very few leases had been taken out; but, in 1825, he reports that 34 new ones had been taken without any reduction from the 10% royalty previously prevailing. At this time, he estimated that the lands under reservation amounted to 150,000 acres. Of this there were leased only 9000. The entire mining district he described as an area about 50 miles square, with Potosi as the center. The reservations were at that time principally about Potosi. For the year 1825, he estimated the production of the state to be 2100 tons of lead [*1, vol. iv, p. 557*].

Lieutenant Thomas defends the system of reserving and leasing lands as generous to the miners, as guarding the resources of the country, and as preventing the monopolizing by foreign capitalists of all of the valuable land. Notwithstanding his activity, however, trespassers and intruders continued to thrive, and, in September 1826, he recommended as probably beneficial, that leases for larger tracts than 320 acres be given; this seems to have been the limit up to that time [*1, vol. iv, p 801*].

In 1827, it appears from the Inspector's report [*1, vol v, p. 5*], that the product of the leased lead mines did not increase. This was attributed in part to the diversion of mining to the upper Mississippi river lead region, which was beginning to acquire importance, and also to the fact that the ore was being exhausted near the surface, though the existence of veins in the rocks had incidentally been proven. But undoubtedly the principal reason why the government's income did not increase, was the inability of the inspector to prevent the unlawful mining on public land. Up to this time, only about 135 tons of lead had been collected as royalty for the past three years [*1, vol. v, p. 144*]. On this account, Lieutenant Thomas was finally led to recommend the sale of these lands. He argued, at the same time, that while attention was concentrated on the rich deposits of the upper Mississippi, the Missouri lands could be sold without danger of their being monopolized. The sale of these lands was also favorably recommended by a congressional committee in January, 1828, and again it was urged through a memorial of the State legislature in January, 1829. Congress was

however, slow to act in the matter, and it was many years before the desired result was brought about.

1830 TO 1850.

The next score of years, up to 1850, was a period of greatly enlarged production. It is also noteworthy as one during which active mining was extended into other portions of the state, beyond the narrow limits of operations heretofore. Thus, the Golconda mine deposits in Franklin county were discovered in 1830, and mining on a small scale began at once. The Virginia mine, in the same county, was discovered in 1834, by Bartlett Brundage [*216, pt. ii, p. 22*], and attracted much attention. Between 200 and 300 miners were employed there during the first year.

About 1843, lead was discovered at Cole Camp, in Benton county, but work was not begun until 1848, and only on a small scale [*32, p. 529*]. In Morgan county, shafts were sunk on Wyan, Trigg and Bryant's land, in Sec. 10, 43 N., 18 W., about 1839, and work had been done in 1837 by some German miners, in Sec. 28, 42 N., 18 W. [*33, pp. 152, 153*]. In Moniteau county, the High Point mine was discovered in 1841. In Cole county, the Old Circle diggings were first worked in 1840 [*32, p. 91*]. In Cooper county, the old Scott mines, on LaMine river, were opened in 1844 [*32, p. 526*]. In Crawford county, the Mineral Hill mines were known in 1837 [*33, p. 251*], and the Halbert diggings were opened in 1844.

In southwestern Missouri, according to one report, mining of lead was begun in 1848, two miles E. of Joplin, by William Tingle; while the first discovery of lead within the limits of Joplin, according to the same report, was by Daniel Campbell in 1849.

Within the old mining area of southeastern Missouri, a few discoveries are recorded. These are How's diggings, in 1840, in Jefferson county, about 5 miles southeast of Rush Tower [*33, pp. 310, 311*]; Frissel mines in 1842, in this county, about 3 miles northwest of Frumet; the Mammoth mines [*216, pt. ii, p. 31*] in 1843, in the same county, about 6 miles southwest from DeSoto, which were the scene of very large operations in the immediately following years; the Avon, in Ste. Genevieve county, in 1848, producing some 8 tons in that year.

In addition to these, there were other deposits discovered during this period, especially in Franklin county; for we know of such having been worked before 1850, though the exact date of discovery has not been obtained. Of such there are cited by Litton [*216, pt. ii, pp. 17–28*]

the Cove, Short, Evans, Mt. Hope, Darby and others, all in Franklin county.

In Washington, Jefferson, St. Francois and Madison counties, new discoveries must also have been made, and many of the old mines continued actively at work. A detailed notice of their operations and productions will not be attempted here, as such matter will be included in the statistical tables and descriptions of mines in subsequent parts of this report; a few of the more important instances will, however, be referred to. Thus, in 1831, it is estimated that 200 persons were in employ at the Fourche a Courtois mines in Washington county. In 1834, Featherstonhaugh [*86, p. 49*] describes the "Taplit and Perry" shaft, in operation 4 or 5 miles from the Valle mine*, The Valle and Perry mines, in St. Francois county, were constant and large producers, as was Bisch's mine also, though the last was not so regular in its operations. In Jefferson county, the Sandy mines were operating in 1832 and during subsequent years, while Lee's diggings, south of the Mammoth mines, were being worked in 1836. Mine LaMotte, in Madison, county was vigorously worked. In 1838 the value of cerussite or "dry bone" is reported to have been first recognized [*147, p. 47*], and gave rise to the erection of new furnaces and an increase of product†. In Washington county, operations were conducted at Old mines and at Shibboleth, though on a small scale during the latter years; also at Bellefontaine, 3 miles E. of Old mines, at Cannon's, Burt's, New Diggings, Casey and Clancy's, Shore's, LaBeaume's, French Diggings and other points enumerated by Litton [*216, pt. ii, pp. 41–54*].

The progress in smelting during these 20 years was most noteworthy, both as regards the improvements of furnaces and methods of work, as well as the increase in their number. At the beginning, in 1830, the old log and ash furnaces were in general use, and continued so until about 1836. In that year, a Scotch hearth was erected at Webster, in Washington county, by Maj. Manning [*216, pt. ii, p. 59*]. This is the first we can find definite mention of (though Schoolcraft refers in 1819 to what was perhaps a Scotch hearth [*203, p. 22*]), and its erection marks an epoch in lead smelting in the state. As illustrating the number and distribution of furnaces, we include the following notes, gathered principally from Dr. Litton's report:

---

*This is probably the same as the "Tarpley" mine, described by Litton as a large producer from 1845 to 1850.

†Though apparently thus late utilized at Mine La Motte, the presence of cerussite had been earlier noted here and elsewhere. Schoolcraft describes specimens from Mine a Burton in 1819, and Troost and Lesueur refer to both the carbonate and sulphate at Mine LaMotte in 1827; they also recognized cobalt in the ore [*223*].

In Washington county, about 1830, the Boase furnace was in operation on Mill creek, and continued during the whole 20 years, a Scotch hearth being introduced about 1840. In 1831, a log and ash furnace was in operation at Webster, and the Scotch hearth was used after 1836. Mr. Evans' furnace at Hopewell started about 1836, and work continued there throughout the period; both Scotch hearth and log furnaces were run. At Old Mines, smelting was in progress since the beginning of mining there. About 1838, a double Scotch hearth was erected there, which produced constantly after that. The Walton furnace, smelting Fourche a Courtois ores, began about 1840, and continued from then on. Creswell's furnace operated in Cold Spring hollow until 1837; it then moved about one mile north of Fourche a Renault postoffice, and work was continued with a Scotch hearth uninterruptedly. Higginbotham's furnace, near the present Fertile postoffice, was in operation from 1837 on; the plant consisted of the old log and ash furnaces, and these were retained for years after 1850. Dunklin's (later McIlvaine's), about one mile S. W. of Potosi, was a Scotch hearth and was in operation after the year 1842. Deane's furnace, near Potosi, was also a Scotch hearth, and was in operation from early in the forties on. At Richwoods, at least two furnaces were run during the last seven years of the period. Murphrey's furnace, one mile S. E. of the present Cruise postoffice, was a Scotch hearth, built about 1848. Kennett's furnace at Shibboleth was built in the same year, and Casey and Clancy's about the same time.

In St. Francois county, furnaces were in active operation at the Valle, Perry and Bisch mines during most of the time they were worked, and large amounts of lead were produced. In Madison county, smelting was prosecuted continuously at Mine La Motte. From 1838 to 1850, 5 smelting furnaces and 2 ash furnaces were in operation, and an additional one between the years 1840 and '47 [*147*, *p. 48*]. In 1842, J. T. Hodge writes that there were 9 "blast" (Scotch hearths) furnaces on the tract, and that 5 more would be built in a few months; in addition, there were 2 cupolas and 1 reverberatory, 4 steam engines and 1 water wheel [*107*, *p. 64*]. In Franklin county, an ash furnace was erected at the Peninsular mine in 1838. Smelting in the Virginia mine was begun about 1835, immediately after its discovery, and was also conducted at other mines in the county. In Camden county, a furnace was erected in 1846, which Broadhead speaks of as probably the first in western Missouri [*32*, *p. 14*].

As indicative of the amounts produced by these furnaces, Dr. Litton gives a large number of figures carefully collected by him [*216, pt. ii, p 63*]. From these it is seen that the total furnace product of Franklin, St. Francois and Washington counties for the years 1841 to '49, inclusive, was nearly 10,000 tons of lead.

Along with this growth of and improvement in the methods of smelting, mining operations grew larger and important appliances were introduced. Deep shafting was undertaken. Featherstonhaugh found a shaft at the Taplet and Perry mine 110 ft. deep in 1834; at the Virginia mine a shaft reached a depth of 260 ft. Steam for hoisting and pumping was in use at the latter and at Mine La Motte in 1844, and without doubt, was employed at other mines. Much crude work continued also, however. Yet, despite the fact that the price of lead fell in the early forties to about 3 cts. per lb., the production continued large and growing, as is shown in the table of chapter XIII of this report.

Data are not at hand from which we can estimate the number of men employed during this period, but it must have been in proportion to the general increase of mining operations.

The ore was still hauled in wagons to the Mississippi river points, and then shipped by boats to various markets. Ste. Genevieve, Herculaneum and Selma were, in the first years after 1830, points of large shipments; but in the latter years of the period, Rush Tower, Plattin Rock, and also Salt Point and St. Marys, were reached.

St. Louis, New Orleans, New York, Boston and other eastern cities were the ultimate destinations of the great bulk of the lead; between 1840 and 1848 considerable quantities were exported to Europe, the largest shipments being in 1844, and aggregating 8223 tons.

During the early years the same system of leasing continued. This had also applied to the upper Mississippi region in Wisconsin; but, after 1834, according to Whitney [*234 p. 405*], in consequence of the immense number of illegal entries, the smelters and miners refused to make any further payments, and the government was unable to collect any more rents. In 1847, the government yielded and decided to offer the lands for sale.

In 1837, an establishment was erected in St. Louis for the manufacture of white lead, by Reed & Hoffman. After a short period the plant passed into the hands of Charless & Blow, from which time we date the founding of the Collier White Lead and Oil Co., through the enterprise of Henry T. Blow. The demands for the paint were small, how-

ever, and the annual product previous to 1850 did not exceed 500 tons. Soon after 1840, Mr. William Glasgrow, Jr., erected works for the manufacture of white lead, by the Dutch process, in St. Louis. Operations lasted only some 5 years, however, for the works were destroyed by fire between 1840 and 1850. Small white lead works were also erected in St. Louis by Bacon & Hyde. During this decade the white lead industry of the United States grew rapidly, and works were erected in New York, Massachusetts, Pennsylvania and Ohio, and became important consumers of the western lead product [*177, pp. 326–328*].

Incidentally worthy of note, as of great future importance to Missouri, is the fact that during this term of years, in 1845, the manufacture of zinc white was suggested by Le Clare in France.

1850 TO 1860.

The salient features of this next decade is the inauguration of the mining industry of southwest Missouri. As already noted, lead ore was known to exist in this region early in the century, and had been discovered in Jasper county, at Leadville, in 1848; while further discoveries at Joplin were made during the following year. About 1851, mining was begun on Center creek, near what was later called Minersville, and what is now Oronogo. Up to 1854, these deposits had yielded only 200 tons of galena; but in that year alone they produced as much again. In 1854, Swallow [*216 pt. i p. 160*] describes the Mineral Point, Mosley and other mines on Turkey creek, as in operation. They were known collectively as the Turkey Creek mines, and were situated a little northeast of Joplin. They were producing then several hundred tons a year.

In the adjoining county of Newton, discoveries were also made, and the developments there in these early years were greater than in Jasper county. In 1850, the Prairie diggings, one mile south of Granby, were started [*32, p. 488*]. In the same year, Mosley and Oldham are said to have raised 50 tons of ore on Shoal creek, five miles northwest of Neosho. In 1854, Swallow writes [*219 p. 36*], that there was not a cabin at Granby, and only one shaft had been sunk. Up to that time the total production of Jasper and Newton counties was 862 tons of lead. This had been produced mostly from galena, though some carbonate was smelted. The zinc ore was all thrown aside. By 1857, however, mining was actively under way at Granby, and in 1858, Swallow estimates that probably 4000 tons of lead had been produced to

date, and, from February to September of that year, Blow and Kennett's furnace at Granby had smelted about 800 tons. Between the years 1851 and 1860, it is estimated that some 300 shafts were put down at various diggings in and about Granby, besides many more at other places in the county.

Along with this development of these two counties, mining was also in progress in other parts of the southwest. About 1856, Shumard [*33, p. 239*] notes that small quantities of lead were mined in Wright county and considerable quantities in Webster county [*33, p. 210*]. In Christian county (then a part of Taney, Webster and Greene counties), there were also quite a number of diggings. Of these, Price and Bray's, located a few miles northeast of the present town of Chadwick, near the present Hornbeak mines, were the largest. They had yielded, up to June 1857, 85 tons of ore. Large quantities of ore were reported to have been discovered in other parts of the county.

Swallow, in his Pacific Railway Report, gives an exhaustive list of all lead mines or occurrences of ore known in 1858, in the counties tributary to that railway. From that list we have prepared the following summary:

Christian county—total No. localities.	14	Mines worked....................	5
Greene " " "	11	" "	..
Lawrence " " "	2	" "	1
Barry " " "	1	" "	..
Newton " " "	21	" "	5
Jasper " " "	14	" "	1
Wright " " "	5	" "	5
	58		17

In the central portion of the state also, some little work was done during this decade. The White diggings, in Benton county, were opened in 1852. In Maries and Osage counties, small amounts of lead had been dug before 1856. In Morgan and Miller counties, also, work was done before 1855 [*33, pp. 22, 34*]. In Moniteau county, lead mines had been opened by 1854 on Dixon's, English's, Powell's, Kelly's and Hart's land; in Cooper county, the Scott mine on the LaMine river had been operated. In Pulaski and Phelps counties, ores were discovered and mined in small quantities by 1856.

In the now comparatively old mining region of the southeast, operations continued uninterruptedly. In Washington and Jefferson counties, about all the mines referred to as operating between 1840 and

1850 continued at least during the succeeding 5 years, and the Valle mine increased its rate of production to over 500 tons of lead in 1858. The same may be said of the mines of Franklin county, and, in addition, the Elliot mine was discovered there in 1853, and the Caswell in 1855.

At Mine La Motte, however, comparatively little work was done, on account of litigation. In 1852, Whitney states that not over 50 or 100 tons were being produced, and not more than 20 men were employed. In Ste. Genevieve county, the Avon mines were operated up to 1850, with a small production. In Perry county, the Wilkinson diggings were worked in 1856. They are situated about 5 miles west of Silver lake. The Horn diggings were also in operation about this time, situated about 5 miles north of the same place.

In 1851, the Williams mine, in Crawford county, about 5 miles east of the town of Bourbon, was opened, and was very profitably worked during subsequent years. At a number of other points in this county, mining on a small scale was also in progress during these 10 years.

According to Mr. Richard Payne, of Ironton, it was in 1855 that a man by the name of Beaugholtz entered the land containing the ore deposits of the Einstein mine in Madison county. It was afterward prospected by him and a man named Lloyd, and later sold to Messrs. Knox and Einstein. According to a prospectus of a company controlling this property, a German miner by the name of Hoeniger sank a shaft here in 1859.

Swallow's list of mines in the country tributary to the Pacific railway includes also those of southeastern Missouri. From this list we have prepared the following summary relating to 1858:

Jefferson county—total No. localities,			42	Mines operated	....	2
Washington	"	"	44	"	....	21
Franklin	"	"	27	"	....	16
Crawford	"	"	33	"	....	13
Phelps	"	"	6	"	....	
Maries	"	"	3	"	....	
Laclede	"	"	1	"	....	1
			156			53

Notwithstanding these facts of development, the appearance of mines in southeastern Missouri was such that so competent an observer as Prof. J. D. Whitney, in describing the mines of Missouri in 1854, says [*234, pp. 418, 419*]:

"All these mines have now fallen off very much, and most of them are completely exhausted, so that but little information can be gathered respecting them, even by traveling through the region.... The lead deposits of Missouri, on the whole, strikingly resemble those of the Upper Mississippi, and the same theoretical observations in regard to the occurrence of the ore will apply to both. As they have been considerably longer worked in the former state, they are now nearer to exhaustion, and there is little reason to believe that they will ever regain the importance which they once had."

The failure of this prediction to materialize need not be emphasized here. As abundant refutation, we simply refer to the tables of production given in the succeeding pages. The cause of this prediction, we assign to inadequate knowledge of the country and of the nature and extent of the developments. No mention is made by Whitney of the then budding industry of southwestern Missouri. The premises seem to have been only brief papers by Hodge and Christy, and a short personal examination of some mines in the southeastern counties.

The field of smelting in the state expanded with the development of mining, and was actively pursued in both the Southeast and Southwest during this decade. On the first discoveries in Jasper and Newton counties, the old methods of log heap and log furnace smelting were resorted to. Thus, the first lead ore treated in Newton county was in a rude log furnace, by A. Spurgeon and others, in the years 1850 to '51. The ore was raised on Spurgeon's prairie, in this county. Other furnaces like this were also in use [*216, pt. i, p. 163*]. These were, however, only initiatory expedients and Scotch hearths (sometimes erroneously called blast furnaces) soon superseded them.

The first Scotch hearth in the southwest was built in 1851, and started early in 1852. It was constructed by G. W. Mosely & Co., and was situated in Newton county, near the mouth of Cedar creek, about 6 miles northwest of Neosho. The ore smelted was from the Mosely mine and from Oliver's prairie, in Newton county, and from Center creek and Turkey creek, in Jasper county. In 1853, the Harklerode furnace was built on Center creek, about 5 miles north of Joplin. Ore from both Jasper and Newton counties was smelted here. The total amount of lead then produced by log furnaces and Scotch hearths, between 1850 and 1854, is estimated by Swallow to have been 776 tons.

These furnaces seem to have been the principal producers of southwestern Missouri during the first few years. New discoveries and extensive developments soon led to the erection of others, however. The most noteworthy of these were at Granby, where Kennett & Blow, in 1856, erected 6 Scotch hearths. Six other hearths were built and operated by other parties. This marks the period when mining in Newton county can be said to have begun to flourish. The production of Granby rapidly rose to 4000 tons of lead per year [*32, p. 488*]. In Christian county, the furnace owned by Messrs. Price & Bray, on Bull creek, was also in operation in 1857. In the southeast, smelting was actively conducted along with the mining. Almost all of the furnaces described in the preceding pages as active in the years before 1850, are described by Litton as large producers during the succeeding four years [*216, pt. ii, pp. 28-62*]. In Madison county, litigation at Mine LaMotte diminished the furnace yields along with the output of the mine.

In 1858, Swallow gives a list of 34 furnaces, distributed as shown in the following table, in 7 different counties [*219, pp. 65, 66*]:

Washington county	No. of furnaces	14
Franklin "	"	4
Jefferson "	"	3
Crawford "	"	1
Christian "	"	1
Newton "	"	9
Jasper "	"	2
		34

Two of the above list are stated to have been log furnaces, 16 are classed as Scotch hearths, and 11 are not exactly classified, but were, without doubt, also Scotch hearths. The blast for these hearths was supplied by water, horse or steam power.

Statistics do not exist from which one can determine the number of men employed in mining and connected occupations during this period, but it must have been proportional to the increased production. Though, perhaps, the number was not much larger in southeastern Missouri, the developments in the southwest must have made a material addition. Thus, in 1858, Swallow states that over 200 men were employed by Blow & Price, in mining and smelting, at Granby, while a much larger

number were engaged in other shafts in that vicinity. The miner was generally paid $16 per 1000 lbs. of ore, and had to pay about $2 per ton royalty.

The lead of the southwest was hauled long distances in wagons to the markets, or to river points. Some went as far north as Boonville, on the Missouri river, and a large amount was hauled to Linn Creek, on the Osage river, while another large portion was hauled to Fort Smith, on the Arkansas river, and then transferred by boat to New Orleans, St. Louis and other markets. Swallow states that the usual cost of transportation from the furnace to St. Louis, at this time, was $1.25 per 100 lbs. It is true that in 1855 work on the present St. Louis & San Francisco railway, then known as the Southwestern branch of the Pacific railway, was begun; but only 18 miles were constructed by 1858, and by 1860 it reached only as far as Rolla, and was thus of little service to the mining interests of the southwest.

In the southeast, lead was hauled during most of this period to the old Mississippi shipping points, but in 1853 the construction of the Iron Mountain railway was begun from St. Louis, and though it progressed but slowly, yet it reached Pilot Knob by 1858, and thus, for several years preceding, was a more accessible line of transportation.

The price of lead during these 10 years was somewhat variable. In 1850, it was $4.60 per 100 lbs.; it rose with fluctuations to $6.19 in 1854, and declined with fluctuations to $5.25 in 1860. As a fact of interest to the lead industry, it is to be noted that the St. Louis shot-tower was also in operation during the latter part of this decade.

The existence of zinc ores in the southeast was well known long before this time, as already stated, and Swallow refers to it specifically in the southwest, and predicts its future value. In New Jersey, the manufacture of zinc white was begun as early as 1860, and in Wisconsin steps were taken about 1859 looking to the utilization of the zinc ores there. Yet, surprising to say, nothing was yet done in Missouri, and the zinc ores continued to lie unused on the dump-piles.

1860 TO 1870.

The lead-mining industry was, apparently, just entering upon an era of great prosperity when it, along with the other enterprises of the country, was prostrated by the civil war. In the southwest, mining was practically stopped entirely at times, that region being so far from, and difficult of access to, the markets and centers of consumption; though the Granby mines and furnaces were worked alternately by the Confederate and Federal forces. In the southeast, this was not so much the case, as the mines were more accessible, and became thus important producers of lead for war purposes. It is true that the United States government destroyed the Mine La Motte furnaces in 1861, but they were soon rebuilt, and, during the four years of 1861 to 1864, over 3500 tons of lead were produced; while, by 1869, with the discovery of the Jack diggings, the production rose to 2188 tons in that year alone. The Valle mines were also producers during this period, though at a diminished rate from the productions of the immediately preceding years. The Darby mines, in Jefferson county, and other mines of the surrounding country, were also operated to some extent.

This decrease of production, combined with the great consumption of lead during the war, had an immediate effect upon prices. At the beginning, in 1860, lead was quoted in St. Louis at 5.25 cts. per pound; in 1862, it had risen to 6.50; in 1863, to 8.62½, and in 1864, it rose to 12.80. In 1865, it was as high as 10 cts., and by 1870 had only fallen to 7.25 cts. Therefore, with the cessation of the war, mining was resumed vigorously. One of the first events of importance was the organization of the St. Joseph Lead company in 1864, at the present town of Bonne Terre. A full account of these mines will be given later in the descriptive part of this report. This company purchased the mines known as the La Grave mines, adjacent to the old Pratt mines, which have been previously referred to.* Active operations began in the following year, but the production did not exceed 240 tons annually [*126, p. 12*]. A steam plant was erected here, and numerous furnaces for smelting the ore; also rock-crushers and rolls for crushing the limestone containing the disseminated galena.

* Mr. Francis La Grave informs us that the first owner of the Bonne Terre mines was a Mr. Aubuchon, who lived during the early part of the century. He transferred the property to one of the Valle family. Mr. Anthony La Grave then acquired possession of it through his wife, who was a Valle, about the year 1852.

In 1865, Henry T. Blow obtained a lease of the Granby mine, and started mining vigorously at once. About this time, a few other mines in adjoining counties resumed work. The St. Louis & San Francisco railway, which stopped at Rolla for a number of years after 1860, was pushed forward again during this decade, reaching Lebanon in 1869 and Springfield in 1870. This was in itself a strong incentive to the development of mines in the whole of southwestern Missouri.

In the central counties of the State, the beginning of active mining may also be considered to date from the last years of this period. In Benton, Hickory and Camden counties, mines were opened. Most of the lead mining in Miller county began in 1869. In Morgan county, Clarke & Bond's furnaces were built in 1867, and O'Brien's in 1869. Thus, though the mining industry was largely suspended during the time of the war, it was not by any means permanently paralyzed, and, with the cessation of hostilities, work was resumed with accumulated energy.

Scotch hearths continued in general use, though at Bonne Terre and other points in the southeast, a form of reverberatory furnace was also used to smelt the cleaned ore as it was delivered from the crude hand-jigs, such as were then universally used. Such jigs even to this day are quite commonly seen in both the Southwestern and Southeastern mining districts.

An event of great importance to the Southeastern district was the introduction of the Diamond drill by the St. Joseph Lead Co. in 1869. It was put in operation at Bonne Terre in that year by Mr. Albert Shepard, who has remained there ever since as an employe of the company. It resulted almost at once in the discovery of disseminated ore at a depth of about 120 ft., and inaugurated the under ground rock mining of these ores in the southeast [*126, p. 17*]. Since that time the Diamond drill has played an important part in the development of the district.*

Zinc ores, we have seen, were beginning to be utilized in Wisconsin as early as 1860, and Matthiessen & Hegeler's zinc works were started, at LaSalle, about 1860; but in Missouri the first metallic zinc manufacture is reported to have been in 1867, by Mr. G. Hesselmeyer, at Potosi [*238, p 112*]. In 1869, the Carondelet zinc works were estab-

*According to Mr. Francis La Grave, son of the former owner of the Bonne Terre lands, some prospecting was done here by him with the churn drill before the war, which showed the existence of disseminated ore at a depth of 80 ft.

lished in St. Louis, and the Valle mine became immediately a large shipper—the zinc ore soon developing into a greater source of profit than the lead ore, heretofore exclusively mined.

1870–1880.

With the end of the preceding decade, Missouri attained a condition of greater activity in lead mining than ever before reached; also, the zinc ores were beginning to be utilized. The condition of the industry and the distribution of lead mining, at this time, is indicated by the following table, extracted from the Ninth U. S. Census:

County.	No. of establishments	No. of employes	Capital	Total wages	Value of product, lead ore*
Cooper	1	2	$30,000	$150	$300
Franklin	25	61	9,250	19,400	27,630
Jasper	1	5	10,000	1,500	37,500
Miller	6	27	3,700	750	6,115
Moniteau	2	5	3,100	350	1,100
Newton	1	300	20,000	50,000	72,500
St. Francois	2	103	78,000	36,879	87,760
Washington	2	27	25,500	13,750	17,000
Webster	2	9	400	1,400	1,980
	42	539	179,950	124,179	201,885

* The values of this table do not agree with the results obtained from railway shipments and other sources of information, as given by Mr. Cobb on pages 682 and 684 of the report of the Mo. Geol. Survey for 1873 to '74. According to these statements, the total value of the pig lead produced by the state for the year 1870 was $1,024,822, which, at 7.25 cts. per lb., represented about 7000 tons of lead, while the census figure represents only about 3500 tons of lead. In the Census reports, however, the production of Mine La Motte, in Madison county, is omitted; as this was nearly 2600 tons for that year, its omission nearly accounts for the discrepancy. Shipments obtained from individual operators show further, however, that the allowances made for other counties are also somewhat too low.

At this time, the Census report states that there were the following lead works in the state:

	Value of product.
One bar and sheet lead establishment	$650,000
Thirty-one pig lead establishments	642,831
Two lead pipe establishments	167,000

Two events of great importance at this time tended not only to maintain this activity, but to increase it. The first was the discovery of ores in great quantity in and about Joplin, the second was the rapid increase in the value and use of zinc ores. In addition, the price of lead continued quite high until the last few years of this decade.

Though mining had been in progress in Jasper county, near the present site of Joplin, for 20 years, it had not assumed large dimensions. Granby had heretofore been the principal mining camp of the southwest. In fact, according to Schmidt [*32, p. 48*], not a single house was standing on the present site of Joplin in 1870. In August of that year, however, according to Messrs. Beatty and Snow, two prospectors, J. B. Sargent and E. R. Moffett, discovered lead ores in large quantities within what are now the city limits. The Moon diggings, on East Joplin hill, were first opened about the same time. The development of these ore-bodies became at once active, and by 1871, several furnaces were kept running night and day to smelt the ores. In 1871 Patrick Murphy bought the land on which Joplin now stands, and the town, first called Murphysburg, was laid out.

Discovery succeeded discovery both in and about Joplin, along Joplin creek, Center creek (Oronogo) and Turkey creek. Thus, by 1874, the population of Joplin had reached 5000, says Schmidt; some 1000 miners were employed, the production was as much as 200 tons of galena per week, and 7 Scotch hearths and 6 reverberatory furnaces were in operation. In the same year, the Memphis, Carthage & Southwestern railway—now part of the St. Louis & San Francisco—was built. In 1875, the Webb diggings, on the present site of Webb City, yielded about 25 tons of ore per week. In 1876, Carterville was laid off, and mining was begun by the Carterville Mining & Smelting Co., on the ground from which such great quantities of ore have since been taken.

Before the beginning of this decade, we have seen that the zinc ores of the Valle mines in the southeast were being utilized. The demand soon reached the southwest. In 1871, an agent of the Missouri

Zinc Co. began to work for zinc near Granby. From Joplin, the first zinc ore is reported to have been shipped to La Salle in 1872, and found sale at once, though at a low figure, beginning at $3 per ton, but soon rising by steps to $15. In 1873, zinc smelting was started at Weir City, Kansas. Dade county also became a producer of zinc ores at this time, and mines in Greene county shipped a little. Thus, by 1875, the production of the state had risen to 23,500 tons of this ore. The discovery and development of the deposits at Galena, Kansas, near Joplin, in 1877, gave an additional impetus to mining, while the sale of ores was further facilitated by the erection, in 1878, of zinc works at Pittsburg, Kansas, by R. Lanyon & Co.

The discovery of the Joplin lead ores first drew mining away from Granby, but the utilization of zinc ores later caused their return, and brought about, not only a renewal of mining operations, but an entire change in the character of the work. Exploitations became deeper and larger, though still of a somewhat crude nature. Up to 1873, fully 1200 shafts had been sunk about Granby; about Neosho there were perhaps about 100 more. Of these, of course only a very small number were operating at any one time. In 1874, some mining was in progress in Barry county. In 1875, the Dade County Mining and Smelting company began work at Corry, and, during the year, shipped 149 tons of lead ore. A circumstance which made the rapid development of these newly discovered ore bodies possible, and which permitted the utilization of the zinc ores, was the completion of the Frisco railway to Peirce City, in 1870, and its extension to and beyond the state line early in the next year.

In the central portion of the state, lead mining continued uninterruptedly. At Linn Creek, in Camden county, a furnace was built in 1871, and was owned by Draper & McClurg; it produced, up to 1873, 1895 pigs of lead. In Benton, a small furnace was also erected for smelting the lead ores of the county, which were then being developed. In the same year work was resumed at the Old Scott diggings in Cooper county, a furnace was built and about 400 pigs were smelted. The Collins diggings, in the same county, were also opened. In 1874, work was resumed at the Marmaduke shaft in Saline county. In Cole county, mining and smelting was in progress at a number of localities; in this and Moniteau county over 20 new openings had been made between the years 1854 and 1874. In 1873, and the immediately succeeding years, most of Morgan county's lead was produced; the Buffalo furnace

was built then, and also the Wyant Spring, Handlin and Otterville furnaces. In all, 7 furnaces and 52 openings were operating in Morgan county, in 1873, employing from 80 to 100 men, and producing over 500 tons of galena in the last half of that year. In Miller county, 2 furnaces and 13 mines were running in 1874.*

In the southeast, this decade was also one of progress and growth of production. In 1870 Mine LaMotte shipped alone 2564 tons of lead. This was much reduced in the immediately following years, owing to the fire in 1872, which destroyed twelve furnaces. In 1876, it rose to 2914 tons. Nickel and cobalt ores were also utilized during this period. Mining and smelting also continued at Valle, Perry, Frumet, Avon and other mines. The St. Joseph mine at Bonne Terre was becoming the scene of large operations. From a production of 22 tons per month, in 1869, the output rose to 122 tons per month, in 1874. By this time 5 shafts had been sunk, and the equipment of the mill machinery and furnaces was largely increased, and the construction of a railway was begun. Two stacks of blast furnaces of large size were substituted for the old reverberatory in 1878. In 1879, the average production per month rose to 350 tons. From this time on the mine continued to rank as the first lead producer in the state. In 1878, the Desloge furnace and mill, adjacent to the St. Joseph works, was started.

In Franklin county, work was in progress at the Virginia and other mines, and, in Madison county, operations were begun on a somewhat larger scale at the Einstein silver mine, in 1874, by Mr. Wm. Einstein.

The methods of smelting during this term changed somewhat from what had prevailed in the past. Fewer Scotch hearths were used, and more reverberatories were introduced, including two or three of the Flintshire type. These were especially used in the Central and Southeastern districts of the state. A number of blast furnaces were also in operation at different points—more particularly for the treatment of slags from other furnaces, and, at Mine LaMotte, specially for the treatment of nickel and cobalt hearth residues. In 1876, Williams describes some 88 furnaces in the state, distributed as follows [*238, pp. 42–80*]:

*For a description of these central counties, see Schmidt's report [*32, pp. 525-576*].

County.	Reverberatory or air furnaces....	Scotch hearths...	Blast or slag furnaces..........	County.	Reverberatory or air furnaces....	Scotch hearths...	Blast or slag furnaces..........
Newton............	4	11	2	Cooper.............	2		
Jasper.............	14	11	1	Moniteau	1		
Dade...............	2			Miller..............	2		
Greene........	1			St. Francois........	9		
Christian...........	1			Ste. Genevieve......	2	.....	1
Cole	4			Jefferson	1	2	2
Morgan	7	1		Washington.........	.....	2	
Camden	1			Madison	.....	2	1
Saline	1				52	29	7

In 1880, according to the Tenth Census, there were only 3 reverberatory furnaces in operation, 61 Scotch hearths and 6 blast furnaces.*

Along with the establishment and operations of these furnaces for the reduction of the lead ores, works were also maintained for the manufacture of lead products, and for the reduction of zinc ore. Thus, in 1875, three establishments were running at Carondelet, namely: the Martindale, Carondelet and the Missouri Zinc Company's works, which operated 1688 retorts, and produced 4650 tons of spelter. Zinc white works were also erected at Hopewell, in Washington county. Outside of the state, in the adjacent country, the LaSalle (Illinois) works were the principal, though 2 plants were in operation in Kansas, by 1880. In St. Louis, in 1873, white lead, shot, pipe and sheet lead works were running.

The general progress since 1870 is best illustrated by comparing the following figures from the Tenth Census, with those of a similar table from the Ninth Census, given on a preceding page:

*It seems hardly possible for such a change in the furnaces used to have taken place during so short a period The only explanation that we can offer is, that in the Census statement the figures for reverberatories and Scotch hearths have been interchanged, as Williams' descriptions leave no doubt as to the character of furnace.

County.	No. of mines.	Total capital.	Total employes.	Total wages paid.	Total products.	
					Lead ore.	Zinc ore.
					Tons.	*Tons.*
Christian........	1	$5,375	60	$12,096	432	
Cole..............	2	575	6	868	30	
Dade.............	3	5,379	115	6,547	48	251
Franklin.........	2	176,000	111	41,000	215	
Greene...........	3	11,730	204	7,670	636	43
Jasper......... ..	29	1,155,540	2,427	1,503,836	10,878	21,304
Jefferson....	4	36,682	24	1,493	56	
Madison.........	2	1,098,797	165	110,063	3,581	
Moniteau........	1	258	2	....	3	
Morgan..........	4	1,766	11	530	64	
Newton..........	1	118,000	442	117,907	1,289	9,550
St. Francois.....	3	843,140	517	172,032	9,844	2,239
Washington......	14	634,862	419	55,754	1,185	606
Wright	2	1,950	19	4,455	54	351
Totals.......	71	4,090,052	4,522	2,035,254	28,319	34,344

	Lead.	Zinc.
No. of smelting establishments ..	30	3 (26 Belgian furnaces, 2628 retorts.)
No. of counties..................	10	1 (St. Louis.)
Tons of ore used.................	35,265	17,123 ($\frac{2}{3}$ silicate.)
Values of ores	$1,729,511	$316,839
No. of laborers..................	600	200
Total salaries....................	$270,000	$125,192
Tons of product: Pig lead	225,530*	Spelter..5,671†
Tons of product: Ni & Co. mattes	19	
Tons of product: White lead.	1,078	
Tons of product: Blue lead......	174	
Fixed capital....................	$787,707	$195,000
Floating capital..................	303,945	55,000

* 72.4 per cent of the ore.

† 33 1 per cent of the ore.

The methods of mining and ore-dressing during this period do not seem to have advanced proportionately to the increase of production, especially in the southwest. The shafts were mostly very shallow and rudely timbered; hoisting was by bucket and windlass with horse and ox-power, though often by hand. Water was lifted out in a similar way. The works were poorly ventilated by cloth tubes, or not at all. Most operations were conducted on leases of small claims, 100 to 200 feet square, the miner working on his own risk and expense, and paying a certain royalty to the general lessee or owner. In the southeast, mining methods were somewhat improved, though the depths reached were quite small, not over 90 ft. at St. Joseph. Steam-power was, however, in use here and at Mine La Motte, and operations were somewhat more concentrated under one ownership and under direct supervision.

With the year 1879, there thus closes a period of unparalleled growth. Operations were then condueted on a large commercial scale and with strong financial support. The extent of this growth is well displayed in the tables of production given later.

1880 TO 1893.

This next fourteen years constitutes a period of continued prosperity in the zinc and lead mining. We have seen that by the year 1880 they were well established among the important industries of the state; the productions of both ores had reached tens of thousands of tons per year, while before this they had been represented by units; and, during this next term, the production of zinc ore has again more than trebled itself, and a material increase in the lead ore production has been witnessed, notwithstanding the fact that during this whole period the price of lead in St. Louis only once or twice reached 5 cts., and was frequently below 3 cts. per lb. Similarly, the price of spelter in New York varied from a little over 4 cts. to about 5½ cts. per lb. In the early eighties, the industry seems to have been somewhat less active, however. Still the progress was noticeable. In the southwest, though few discoveries of new districts were made, new ore bodies were constantly developed, especially in Jasper county. About the year 1880, the St. Louis & San Francisco, the Mo. Pacific and the Kansas City, Fort Scott & Memphis railways were extended into this county. Mining was vigorously prosecuted, and the production soon surpassed that of Newton county, and threw Granby into the shade. Camps multiplied about Joplin, and in the comparatively new ground

of Carterville and Webb City, along Spring river, Center creek and Turkey creek, and especially about Galena, across the state line in Kansas. The mines were so numerous, and the openings controlled by one operator changed hands so often, that a specific reference to the history of each, even of the larger, will not be practicable. Important facts of this nature will be incorporated later, in the statistical and descriptive portions of the report. The mines gradually grew in size as ore bodies were followed, especially about Carterville and Belleville; they remained no longer the small gopher holes which characterized the region in the early years of mining. By 1890, the population of Joplin had grown to 10,000, that of Webb City and Carterville to 8000, and that of Carthage to 8000 also. In 1892, Jasper county produced over 100,000 tons of zinc ore, which is more than $\frac{3}{4}$ of the total production of the state; and over 11,000 tons of lead ore, which is nearly $\frac{1}{4}$ of the state's production. Early in 1886 the mines at Aurora, in Lawrence county, began to be developed. The place at that time was not much more than a flag station on the railway, but its population rose by the year 1889 to 3400. The mines there are now important producers of ore, their output of both lead and zinc ores in 1892 amounting to $\frac{1}{10}$ of that of the whole state.

Other southwestern counties were also producers of both lead and zinc during this period, especially Greene and Christian counties.

In the southeast, the St. Joseph mine continued to grow in importance. Despite a disastrous fire in 1883, which destroyed the mill and other works about the mine, the production increased steadily until, in the year 1892, it reached over 21,000 tons of lead ore, equivalent to more than $\frac{2}{5}$ of the total state production. The adjacent Desloge property, the mill of which was destroyed by fire in the winter of 1885–86, was purchased and consolidated with the St. Joseph company in 1886. After the fire of 1883, large and improved works were designed, including a series of powerful rock crushers, Cornish rolls, elevators, screens, steam-jigs, etc. These are now erected and have been operating for a number of years. The ore treated contains on an average about 6% of galena.

Mine La Motte was also a steady producer during this period, and its productions increased somewhat over the preceding decade—the mines yielding in 1892 4403 tons of ore.

Among the extensions of mining is to be noted the opening of the Doe Run mine, near Farmington, in 1887, and also the development of

the deep disseminated ores of Flat river, south of Bonne Terre, during the last few years. The construction of the Mississippi River and Bonne Terre railway, from Riverside to Doe Run, has done much to stimulate developments at the last two localities. It was completed in 1890, practically by the St. Joseph Lead Co., and enabled that company to move its furnaces from Bonne Terre to Herculaneum, where the facilities for smelting are much better.

In the Central district, comparatively little work was done, and this was of an intermittent character. The figures of the Tenth Census, given on page 298, indicate that the production was small in 1880, while those of the Eleventh Census for 1889 make a still smaller showing. The mines of this district were worked with much profit while lead commanded the high prices prevailing before the year 1878. Since that time, they do not seem to have been susceptible of profitable working.

The following table, prepared from the report of the State Mine Inspector, Mr. C. C. Woodson, for the year ending June 30, 1892, well illustrates the status of the industry at the present time:

County.	No. mines.	Total No of employes.	Total product.	
			Lead ore.	Zinc ore.
			Tons.	*Tons.*
Barry	4	30	84	192
Cole	......	....	35	....
Dade	......	....	99	104
Franklin	......	....	150	....
Greene	7	43	406	899
Jasper	437	3,624	11,501	106,014
Jefferson	25	120	413	2,075
Lawrence	116	819	5,720	13,861
Madison	3	292	4,403	....
Miller	......	....	25	....
Newton	77	432	1,250	8,343
Perry	2	4	6	....
St. Francois	6	551	23,740	....
Washington	......	....	1,794	....
	677	5,915	49,626	131,488

The metallurgy of lead continued about the same in method during this period, with a decrease of plants in the central counties and an increase in the southeast.

For zinc, smelting plants were erected in 1881 at Rich Hill and West Joplin. In 1882, according to the Mineral Resources of the U. S., three plants were in operation in Illinois—at Collinsville, Peru and La Salle; five in Kansas, four being at Pittsburg and one at Weir City; and five in Missouri, three of which were at Carondelet, one at Rich Hill and one at Joplin. All of these were using Missouri ores to a greater or less extent, though they were not all active at the same time, particularly during the first five years. In 1887, zinc works were started at Nevada, Missouri, and new works were being built at Scammonville and Girard, Kansas. In 1892, a plant was built at Galena, Kansas.

In the methods of mining there is considerable improvement at some localities. Steam power is commonly used in the southeast, and also in the southwest, but in the latter region horse or man power are more frequent. The shafts still remain roughly excavated and poorly timbered, and the rope and bucket are still in almost universal use. Steam crushers, rolls and other important machinery have been introduced in some of the plants in the southwest. Much, however, remains to be done in the way of improvement of mining and preparing of the ores.

The same sytem of subleasing small tracts of land prevailed, though there are a few instances, as with the Empire Zinc Co., in which the owners operate the lands themselves systematically and on a large scale. In 1882, according to Mr. Clerc [*240, p. 370*], royalties of 25% on blende and 50% on galena were paid to the land-owner, and, where pumping was done, there was an additional tax of $1 per ton of zinc ore and $2 per 1000 pounds of lead ore. At present the royalties range up to this amount in certain cases, but they are generally less than this, the amount being dependent upon the ease of mining and the quantity of ore available.

CHAPTER VIII.

THE PHYSIOGRAPHY OF THE MINING DISTRICTS.

THE SOUTHWESTERN DISTRICT.—THE SOUTHEASTERN DISTRICT.—THE CENTRAL DISTRICT

Within the borders of the three districts are included the three types of topography which are recognized in the state. These we designate as: 1) the Prairie country; 2) the Plateau country; 3) the Highland country. Each of these types has features which are represented in the others, and each has features which distinguish it. The combination of these results in the production of countries of entirely different aspects.

The prairie country is represented principally in the Southwestern and Central mining districts—in the western and northern half of the former, and in the northern half of the latter. Here, the country assumes the character of a broad undulating plain, with a sparse growth or entire absence of timber over wide stretches. Adjacent to the larger streams it loses its characteristic features to a certain extent, as will appear later.

The plateau country occupies principally the southeastern portion of the Southwestern district, and the southern half of the Central district; it may also be recognized, though in not so pronounced a form, over portions of the Southeastern district. It differs from the prairie country chiefly in its greater relative altitudes and in the more vigorous sculpturing. The valleys are deeper and the slopes more abrupt, while between the depressions are comparatively flat plateaus and ridges.

The highland country belongs exclusively to the Southeastern district, and consists essentially of a series of knobs or domes, irregularly distributed and covering a comparatively small area. It is distinguishable from the preceding types in the form, structure and age of the features of relief.

The drainage of the three districts is into three large rivers, *i. e.*, the Mississippi, Missouri and the Arkansas. The first two are contiguous to the Southeastern and Central districts. Several large streams, however, traverse each of the districts, and will receive due consideration later.

The forestry of these districts is not remarkable for size or variety of timber. Over the prairie country the growth is not abundant, nor are the trees large. Over the plateau and highland countries, the growth is frequently dense, consisting principally of varieties of oak. These trees, though large enough to be valuable for ordinary uses, are not such as to support a great timber industry.

Pines are found in the southern part of the Southeastern and Southwestern districts. In the rugged country adjacent to the streams there is a scattered growth of cedars, which is of commercial value.

The soils of the upland country are essentially all residuary. Along the larger streams are usually broad alluvial plains of very fertile land. The prairie country is normally a good one agriculturally. Much of the upland of the plateau country, as well as the subordinate hills along the valleys, is covered with a good soil; here, however, many ridges have a thick covering of chert fragments, which unfits them for most agricultural uses. The soils of the highland country are thin over the hills and mountains, but the valleys often contain good farming lands.

THE SOUTHWESTERN DISTRICT.

The whole of this district may be regarded as a plain, composed of nearly horizontal strata, now deeply incised. It is, however, not a level plain, but is tilted from the east toward the west, the altitude of the surface at Cedar Gap, near the eastern border, being about 1700 ft., while at Joplin, near the western border, it is only 1000 ft. The extremes of elevation are that at Cedar gap, above given, and that where White river leaves the State, which is not much over 700 ft. The local differences of elevation amount frequently to as much as 300 ft. within the same square mile.

Topography.—The topography of the district belongs mostly to the prairie type, but the plateau is also represented. The former prevails over the Lower Carboniferous and Coal Measure areas shown on the district map, but it also extends over the Lower Silurian portions of Greene, Polk and Webster counties. Similarly, the plateau belongs

principally to the Lower Silurian country of the southern and western parts of the sheet, but it also includes portions of the Lower Carboniferous of Barry, Stone, Taney and Christian counties.

The Prairie Country.—This extends from Webster county west through Polk, Greene, northern Christian, Dade, Lawrence, northern and western Barry, Barton, Jasper, Newton and McDonald counties. This, though designated a prairie country, is by no means a flat plain, and its difference from the plateau is more one of degree than of kind. It is almost everywhere undulating. Its range of altitude within the limits fixed amounts to nearly 700 feet., and local differences of 100 ft. within the same square mile are common. The river valleys are bordered by bluffs, but these are not so high as in the plateau country, and the transition from plain to valley is not so abrupt. The rivers are characterized by comparatively broad and generally continuous meander plains.

It is between the principal streams, however, that the characteristic features of the prairie country are developed. Here, we have broad expanses of nearly flat land traversed by swales or depressions, along which the minor streams or rivulets flow. No ridges, buttes or other eminences rise above the general level. The surface is treeless over wide stretches, and makes an excellent farming country. The timbered portions are principally along the minor depressions, and, also, amid the breaks and the foot-hills of the larger streams; over the upland plain some patches of timber occur at intervals, also. Part of this surface is bald and bleak, with a thin soil, and suited only for grazing purpose.

The river valleys are composed of flat alluvial plains, and of minor elevations and foot-hills, which form an escarpment, rising to the plain above. These alluvial plains are generally less than a mile wide. They were originally largely covered with a growth of heavy timber; this is now mostly cleared, and the lands constitute the richest farms of the district. They are not always continuous, but the valleys are sometimes so contracted that the stream flows through a narrow gorge. This is noticeably the case along the lower stretches of Shoal creek. The reason for this is plainly seen to be the presence of a massive bed of chert, through which the stream has had all it could do to cut the narrow channel.

A prominent feature, and one developed in the plateau country also, though to a greater degree, is the steepness of the hills adjacent to the stream valleys. Sometimes, it is true, the country slopes gradually down to these valleys; but, as a rule, there is a well-defined escarpment, which one ascends as one would a flight of stairs, to land on the platform-like plain of the prairie country above. The reasons for this are largely in the geologic structure of the country, and will be referred to at the end of this chapter.

The Plateau Country.—This name is applied especially to the country tributary and contiguous to White river. It is typically represented in eastern Barry, in Stone, Taney, southern Christian, Ozark and Douglas counties. It is principally distinguishable from the last by the boldness of the relief and by the range of altitude—the extremes being 1700 ft. at Cedar Gap and about 700 ft. on White river, and the local ranges amounting to over 300 ft. within the same square mile. The streams are much deeper incised, and with small or no flood plains among them; they are very tortuous, with uplands projecting into the loops, as will be described and discussed later.

This stretch of country has recently been in part mapped and critically studied by Mr. C. F. Marbut, Assistant Geologist of the Survey. On the topographic sheet prepared, its features are admirably brought out. He divides these into "1) an upland plain, gently declining to the westward; 2) an escarpment terminating this plain on the east; and 3) a second more or less incised plain (the Magnesian limestone plain), lying below the escarpment and stretching from its base eastward, beyond the limits of the area."*

1. The upland plain between the larger streams is not different in appearance from the prairie country, though it is more sharply defined by the escarpment line, from which the fall is between 300 and 500 ft. to the plain below. As Mr. Marbut expresses it, this plain, and also the one below, "have been dissected by the erosion of the streams so that very little of the surface is left uncut. The escarpment line has been driven backward around the heads of the streams flowing out of the upper plain, until it is very irregular. This plateau is an exceedingly level surface. Standing on a high object which raises one above the forest, and which gives one a distant view of sky line, it is, apparently, absolutely level; not relieved by the faintest ele-

* This is not the White river valley, but corresponds approximately to the surface of the Lower Silurian rocks, where entirely stripped of the Carboniferous limestones It is always 200 to 400 ft. lower than the Carboniferous plain, and it rises eastward. White river valley is sharply incised in this lower plain. C. F. M.

VIEW IN THE PLATEAU COUNTRY.

LOOKING UP ROARK CREEK FROM DEERLICK MOUNTAIN, STONE CO.

THE ESCARPMENT IN THE PLATEAU COUNTRY.

From photograph by W. P. Jenney.

vation. This upland plain is the divide between the water flowing southward into White river, and that flowing northward into the Missouri. The character of the surface on opposite sides of the main divide is very different. The slopes of the southern side are very steep; the streams have a great fall, and the hollows which lead up to the divide are narrow and very deep. The northern side slopes more gradually; the streams do not follow narrow deep canons, but rather wide open basins. On the southern side, White river flows near the divide, the streams are short and the fall is great. On the northern side the drainage is into the Missouri, and the streams have a long distance to traverse before reaching it. The fall is, therefore, greatly reduced, and also the erosive power. Transportation hardly keeps pace with the atmospheric degradation, and we have a rolling country with a deep soil and shallow valleys."

2. "By escarpment we mean a steep slope terminating an upland. The idea carries along with it the two plains, an upper and a lower one, both being gently inclined. The escarpment here described is determined by the more rapid weathering of the basal beds of the Lower Carboniferous limestones. These weather out, thus undermining the higher, more resistant beds, which break off in great blocks, leaving a steep face. Its base coincides with the contact between the Lower Carboniferous and magnesian limestones shown on the geological map."

"It enters the state on the southern line of Barry county, whence it runs northeasterly through Barry, Stone and Taney, reaching its farthest eastward extension in Wright county, near Cedar Gap. Its course so far is an exceedingly irregular one. It runs up the valleys of all the streams flowing into White river, making a series of sharp-pointed embayments extending into the Carboniferous plain. From near Cedar Gap, it runs northwestward to Marshfield. Its character changes somewhat here, on account of the presence along this part of its course of the Hannibal sandstones and shales. It remains, however, well-marked topographic feature."

"South of White river, the escarpment enters the state from Arkansas and runs in an irregular line through Stone and Taney counties, again passing out of the state about the middle of the southern boundary of Taney county."

"From Cedar Gap southwestward the escarpment will average 200 feet in height. In many places it is higher, but there are comparatively few places where it is lower. At Cedar Gap, as shown by the railway

profile, the fall is about 200 feet. From Cedar Gap to Marshfield the height will average about 120 feet. Over that part of its course where it is highest, it consists of an upper, steep, cherty slope of 150 to 175 feet, with a cliff below of about 25 feet to the base of the Carboniferous rocks. This is the base of the escarpment proper, though there is generally a gradual slope over magnesian limestones, of from 0 to 150 feet, to the general level of the Carboniferous plain."

3. "The features of the lower plain lying east and south of the escarpment are somewhat different from those of the upper plain. Its surface away from the larger streams is strongly undulating. The small branches flow in wide depressions, and not in narrow, steep ravines, as on the southern side of the upper plain. Near the larger streams it is deeply incised. The valleys are narrow. Even of White river, the largest stream in this part of the state, the valley is but little wider than the river channel. The valleys are bounded, in almost all cases, by at least one precipitous wall. From the top of the precipice, the plain stretches away, rising gradually toward the Carboniferous contact, where it is abruptly terminated by the escarpment — in many cases precipitous, in all cases steep. This lower plain extends along the larger creeks flowing out of the upper plain, as a bench of varying width, on one or both sides of the stream, lying between the narrow valley of the stream on the one side and the escarpment on the other."

"In the vicinity of White river, there is a series of conical hills or buttes almost bare of vegetation on which every stratum of limestone shows as a narrow terrace running horizontally around the hill. All along White river, these hills form a marked feature in the topography."

"The characteristic features of this plain are thus: *a*) the undulating surfaces away from the large creeks; *b*) the flat, trough-like valleys of the small branches; *c*) the sharply incised valleys of the large streams, and *d*) the rounded terraced hills near the escarpment and along White river."

Hydrography.—The streams of the Southwestern district, with the exception of White river, are all quite small, and even that one cannot be classed as navigable above Forsyth. They all belong to one or the other of three different drainage systems: *i. e.*, those of the Missouri, Arkansas and White rivers.*

* The White river, though strictly speaking a tributary of the Arkansas river, enters the latter stream so close to its mouth, that to all intents and purposes it is a separate river.

SPRINGS OF THE PLATEAU COUNTRY.

From photographs by W. P. Jenney.

The divides separating these different drainage basins from each other are clearly shown on the small drainage map on page 320 of this report. Those streams belonging to the Missouri river system, beginning with the eastmost, are Lick fork, Osage fork, both tributaries of the Gasconade river; and the Niangua, Pomme de Terre and Sac rivers and their forks, all tributaries of the Osage river. The streams belonging to the Arkansas river drainage system are Elk river, Shoal creek and Center creek and their forks, all tributaries of Spring river, the head-waters of which drain the northwestern corner of the district. The streams belonging to the White river system are White river itself, and James river, King river, Swan creek and Big Beaver creek and their forks, all flowing into White river within the limits of the district. Though none of these streams are large enough to be freely navigable, both White river and Spring river furnish transportation to flat-boats, and are utilizable for rafting. In times of high water, they develop into streams of great depth and volume. Spring river, where of any size, extends so little into the state that a description of it is omitted.

White river, within the district limits, has a fall of about 3 ft. to the mile—its altitude where it enters the state being about 1100 ft. A. T., and where it leaves the state, some 125 miles further down, about 700 ft. A. T. The declivity is, however, not absolutely continuous, but is interrupted by a number of shoals, which make boating difficult at times. Between these shoals are long pools, frequently of deep water. At one of these shoals, known as Elbow shoal, about 50 miles below Forsyth, the fall amounts to as much as 4 ft. in 1000 [*228, vol. xvii, p. 123*].

The other streams within the limits of the district, with perhaps, the exception of James river, are very small and not easily continuously navigable, even by skiffs. Some of them go almost entirely dry during times of drouth; but others are kept alive by the numerous springs which characterize this limestone country, and which frequently gush out beneath limestone bluffs in great volume. Many such streams, where the declivities are great, are destined to become valuable sources of power; even White river can in places be thus utilized. The most noteworthy instance of such utilization of power is at Grand falls, on Shoal creek. Here a large power plant has been erected, from which electric lighting is supplied the city of Joplin, and hoisting power to a number of mines.

The streams of the prairie country and of the area of the Carboniferous limestone have, in large part, reached base level, and are developing meander plains, as has already been described. In places, such leveling is evidently only down to a temporary base, caused by some obstruction to the corrasion of the channel lower down the valley. Other streams, particularly those of the plateau country and of the Lower Silurian magnesian limestones, are still corrading and lowering their channels.

With White river, the largest, corrasion is still in progress, and some peculiar features are attributable to this cause. A study of topographic maps of this country, as stated by Mr. Marbut, would show that "through all its course in Missouri, White river flows in an exceedingly narrow and very tortuous valley, about 500 to 600 ft. below the top of the highest plateau, and from 250 to 450 ft. below the base of the Lower Carboniferous rocks. Probably without an exception, the outside of each curve of the river valley is bounded by a sheer precipice, often reaching a height of 300 ft., while the inside is a sloping point, sometimes a rather steep one, extending into the bend to the river, with, in some cases, a narrow flood-plain on this side of the stream. As is shown on the drainage map, this remarkable system of meanders forms a noticeable feature of the stream. When it is remembered that these meanders are not on a broad flood-plain, but are sharply incised in the upland, with the high land extending into the bends, often to the river's edge, additional interest attaches to them."

"The tributaries of White river within the area are numerous; all have the same characteristics as White river. On the southern side of White river is Kings river, a stream of considerable size, draining the northern slope of the Boston mountains in Arkansas, and having only a short course within the state of Missouri. It meanders in a deep narrow valley, essentially the same as White river. Farther eastward, are the two Indian creeks, Cow creek and Long creek — the latter, a stream of considerable size, draining the country around Carrollton, Arkansas, and flowing into White river near the Stone-Taney county line. Turkey creek and Bee creek, east of this, also flow into White river from the south."

"On the northern side we have, commencing in the western part of the area, Roaring river, Rock creek, James river, Roark creek, Bull creek, Swan creek and Big and Little Beaver creeks. James river is the largest tributary from this side. It is a stream of about the same

size as Kings river, and has a series of well-developed meanders. The other streams east of this have no very marked meanders."

Soils.—The soils of the Southwestern district are both transported and residuary. The former are confined to the alluvial plains of the streams already referred to, and consist generally of a rich, dark loam, overlying a chert gravel. This constitutes very fertile lands, which are valuable when not subject to disastrous or long continued overflows. This is a great objection to such lands in the White river country. The soils are made up of comminuted particles of rock from different portions of the drainage area. With these is frequently mixed much vegetable matter.

The residuary soils are derived from the decay of pre-existing rocks, which are generally the same as those at present immediately underlying the soil. Such soils, hence, vary with the character of the country rock, but they are also modified by the shape or slope of the surface.

Over the Coal Measure patches, much of the soil is of a sandy nature, being derived from the sandstones of the lower part of this formation.

Over the area of the crystalline and massive Lower Carboniferous limestones, good loamy soils prevail where the declivity is not so great as to wash the rock bare. In those areas occupied by the shales which constitute the base of the Lower Carboniferous, good soils are also found. Those areas which are immediately underlain by the other cherty members of this formation have a very thin, poor and rocky soil, especially where the slope is sufficient for the finer materials to be readily washed away. In many cases, the ground is literally covered with chert fragments, and absolutely no soil can be recognized. Such conditions are more prevalent over what we have defined as the escarpment area than elsewhere.

Over the magnesian limestones, good soils are also found when the conditions have allowed the accumulation of a considerable thickness. In many places, especially in the plateau country, these soils are noticeably very thin, and great ledges of rock are laid bare, and many bald hill summits or knobs occur, which are characteristic features of the country. In some cases, the entire slope of a hill is totally destitute of vegetation, and the successive strata of hard rock stand out in clearly defined terraces, from top to bottom.

Forestry.—The most timbered portion of the district is in the southeastern quarter, or in the plateau country; but all of the area, excepting perhaps the extreme northwestern quarter, is a timbered country. In fact, the Tenth Census gave as the density of the greater part of the area, 50 to 100 cords per acre, while that of the balance was from 20 to 50 cords. The principal growth is of oaks, but we find here also walnuts, hickories, ashes and chestnuts, and, in the extreme southern part, some pines. The following description of the plateau country, as given by Marbut, conveys a good idea of the forestry of the whole area:

"The forestry of the magnesian rocks is not of sufficient value to receive much notice. In some places, over a small territory, where there is a good accumulation of soils, there is a forest of young black and red oaks, principally the latter, excepting on cherty ridges, where the former predominate. To the east, where the surface of the magnesian rocks has been longer exposed and has a deeper soil, there is some very good timber. The lack of timber is, however, not altogether on account of the nature of the soil, but is often largely due to the lack of soil. The soil of these rocks, even where heavy enough to support a good growth of timber, is, however, not so good for that purpose on account of its clayey nature, and, in many places, its lack of cherty material, which insures good drainage. The principal trees are the red oak, black oak, white oak, post oak, elm, walnut, wild cherry, etc."

"By far the most valuable timber left within the area is on the chert hills within the Carboniferous rocks. When far enough removed from the railway, there are considerable areas of practically untouched oak and a considerable amount of pine of the short-leaved kind (*Pinus mitis.*)"

"All the southern part of Stone county, south of the mouth of Crane creek, the eastern part of Barry county and all of Taney county, where there are Carboniferous rocks at the surface, is yet covered with forests of black oak and white oak, which, with convenient means of transportation to market, would be valuable. The rest of the area underlain by Carboniferous rocks north, northwest and northeast of these sections, lies too near the railways to have much valuable timber yet standing. Chadwick, on the St. Louis & San Francisco railway, and Seymour and Cedar Gap, on the Kansas City, Ft. Scott & Memphis railway, have been the shipping points for these products. The timber of most value, excepting the pine, is the white oak, and, while there is

not enough to warrant the erection of large mills, yet, if there were sufficient means of transportation, it would furnish the basis for a considerable industry for several years."

"The pine timber is confined wholly to the area of the chert hills of the Carboniferous rocks. South of Kirbyville, in Taney county, and extending westward along the southern line of the county to Indian creek, is the most considerable body within the area. Another patch lies on the hills east of Marble cave, in Stone county. With this last exception it is confined to the southern side of White river, so far as my observations extended."

THE SOUTHEASTERN DISTRICT.

The surface of the Southeastern district differs from the Southwestern, in that it is dome-shaped instead of being a tilted plain—the slopes being radial from a center in the southern portion. The drainage, following these slopes, is, hence, also radial. The greater part of the topography does not belong to a distinct type. One part, occupied by the Archean rocks, is typically highland; the remainder is a combination of the highland and plateau types, with some suggestion of the prairie country over certain portions. The extremes of altitude within the district are: 1800 ft. A. T. on the summit of the Taum Sauk mountain, and 400 ft. along the Mississippi river. The slope eastward is, hence, quite steep.

Topography.

The Highland Country.—This type of country has been fully described in the recently published Iron Mountain Sheet report. A brief notice will, hence, suffice here. As already stated, it is confined to the Archean area, which extends southward beyond the limits of the district map. The elevations or hills are composed of granites or porphyries, while the intervening valleys are underlain by Lower Silurian strata, principally of magnesian limestone. The hills, which may be considered small mountains at times, rise to heights of from 600 to 800 ft. above the surrounding valleys. The larger of these are frequently irregularly shaped masses, while the smaller are somewhat conical knobs or domes. These features of relief are distributed irregularly, and are evidently the results of the erosion of massive rocks, unguided by structural planes. The valleys are correspondingly irregular in distribution and shape. They have uneven surfaces composed of small

hills; few or no flood plains are developed along
sometimes they flow through narrow gorges, between

The Plateau-Prairie Country.—Away from the over almost all of the Southeastern district, as ha country is of an indefinite type. The surface is to much trenched by valleys to belong to the prairie the upland plains of the plateau, but is made u irregularly distributed as in the highland countr tude and prominence. In the northwestern po the vicinity of the Meramec river, more of the is found. As a whole, however, the district is sected plain, in which denudation has develo beyond that of the plateau type.

The hills and valleys are the only f here, and these are not always clearly de hills are of irregular shapes and outlines, a developed between the streams of a very They are ordinarily about 200 ft. above country. They can be recognized eastwa sissippi and Missouri rivers, where they f ing the flood plains of those streams.

The valleys are mostly undulatin hills. The streams flowing in these h plains, though in the northern part, alo these are much expanded.

Hydrography.—Almost all the ries of the Mississippi river. The creeks in northwestern Franklin co river, and the heads of Black river

Only two large streams travers and its tributaries the Bourbeuse Francois river. The Meramec is The others are not, though the Francois river can be traveled floating lumber. The fall of th trict to the mouth of the Bou Big river, from near Irondal mile; below this the decliv

the prairie
of these belong
magnesian limestones.
northern half of the
beyond the head-waters of
and the heads of these, a bold es-
following approximately the di-
on page 320. In Cole and northern
of the district is dissected by the Mo-
its prairie characteristics. In the
Laclede county, the country belongs,
The characteristic features of an un-
patches, etc., as described in the South-
here also. They need not be redescribed.
much of the prairie country, and there are,
to break its continuity.
that traversed by the Osage river and its
The characteristics disappear as one recedes
On the north, the change from the flat upland
deeply trenched plateau country is sharp, and the
escarpment already referred to. On the south

form, but the streams consist of alterations of pools and shoals. Along some of the latter, water-power can be developed.

Owing to the altitude of the central portion and to the proximity of the low-lying Mississippi river, the fall of many of the streams of the eastern half of the district is great. The St. Francois river, from Delassus to where it leaves the district, has a fall of as much as 12 ft. to the mile. Saline creek, from Avon to St. Mary's, on the Mississippi river, falls over 400 ft. within a channel length of little over 20 miles. Other streams of Ste. Genevieve and Perry counties have like declivities, though the great portion of the fall is, of course, in the upper stretches. Opportunities for the development of water-power are, hence, good, and are utilized at a number of points. The most noteworthy of these is at the Einstein silver mine, where a granite and cement dam is constructed, producing a fall of 22 ft. Several hundred horse-power can be obtained here. The water of most of these streams is clear, and of excellent quality for all uses. The streams ordinarily flow over gravel, consisting largely of chert, and great banks of such material have accumulated along the valleys.

Because of this declivity, the streams are generally still corrading their channels vigorously, and flow frequently through canon-like gorges. This is especially the case in the Archean area of Madison county. The upland meanders, which we have described as characterizing White river in Southwestern Missouri, are well developed here along Big and Meramec rivers, as is indicated on the map. The peculiar details have been beautifully brought out upon maps, recently constructed by the Geological Survey, of portions of this district.

Soils.—The soils of the Southeastern district are somewhat closely comparable to those of the plateau country of the southwest. Those of the uplands are residuary, while those along the river bottoms are transported. As in the southwest, the soils are derived largely from magnesian limestones. Chert is less prevalent, and there are less bare rock surfaces. Many stretches of excellent farming lands exist, particularly over the low-lying portion of the country. The higher ridges are more sterile and rocky. The soils of the Archean hills are particularly poor, being thin and clayey, and often little more than a mass of porphyry fragments.

Forestry.—The forest growth is also similar to that of the Southwestern district; though the country is, perhaps, more timbered, the hills being almost entirely covered. Red, black and white oaks char-

acterize the uplands; hickory, elm and sycamore, the creek bottoms. Large quantities of timber have been cut in past years, and made into charcoal for the iron furnaces at Iron Mountain, Pilot Knob and in Crawford county. The various lead furnaces, which have been worked for nearly two hundred years, have also drawn quite heavily upon the timber supply. Much tie-timber is now cut all over the district, and hauled to the nearest points. Walnuts, though occasionally found, are not abundant, and not of industrial importance. In the central-southern portion of the district, in the vicinity of Hogan, the northern limit of the pine region of the state is reached.

THE CENTRAL DISTRICT.

The Central district, like the Southwestern, is an incised, tilted plain, which slopes to the north. The summit altitudes along the southern border are about 1200 ft.; while about Sedalia, on the northern edge, they are 900 ft. As a measure of the depth of erosion, the maximum altitude is about 1360 ft., the minimum, 400 ft. Local differences of elevation of 300 and 400 ft. are common.

Topography.—Here, as in the southwest, we have both the prairie and plateau types well developed; but here both of these belong almost entirely to the area of the Lower Silurian magnesian limestones.

The prairie country belongs principally to the northern half of the district, north of the Osage, and mostly beyond the head-waters of its short northern tributaries. Around the heads of these, a bold escarpment is plainly traceable, the line following approximately the divide shown in the drainage map on page 320. In Cole and northern Moniteau counties, this portion of the district is dissected by the Moreau and other creeks, and loses its prairie characteristics. In the extreme southern part, in northern Laclede county, the country belongs, to a certain extent, to this type. The characteristic features of an undulating surface, broad, treeless patches, etc., as described in the Southwestern district, are present here also. They need not be redescribed. No large streams traverse much of the prairie country, and there are, consequently, no river valleys to break its continuity.

The plateau country is that traversed by the Osage river and its immediate tributaries. The characteristics disappear as one recedes from these streams. On the north, the change from the flat upland prairie plain to the deeply trenched plateau country is sharp, and the line is marked by the escarpment already referred to. On the south

the change is more gradual. The features of the plateau country of White river are almost perfectly reproduced here, excepting, perhaps, for the absence of the "bench" described by Mr. Marbut. We have here the same deeply eroded, sinuous valleys, though flood plains along the larger streams are somewhat broader than in the southwest. The uplands are also somewhat narrower, consisting frequently of long, "hog-back" ridges. The valleys are, further, not so deep, generally not over 200 or 300 feet below the adjacent summits. The country is timbered throughout.

Hydrography.--The area, as shown on the map, is bounded on one side by the Missouri river, and into this stream all drainage flows. It is traversed by two large tributaries, the Osage and the Gasconade. The Missouri river flows through broad bottom lands bounded by bluffs. It is generally navigable, though, during some autumn and winter months, low water and ice prevent travel. Moreau creek is the only considerable tributary in the district, above the mouth of the Osage. It is characterized, in places, by comparatively broad flood plains, and has a peculiarly intricate system of upland meanders. The fall is considerable, and water powers could probably be obtained at a number of points.

The Osage river is one of the most interesting and picturesque streams of the state. It is navigable much of the time from its mouth to beyond the limits of the district, and almost all the time as far as Tuscumbia. Within the district, the width of the channel increases from 400 to about 1000 ft. at the mouth. The declivity to Tuscumbia is nearly a foot per mile, while thence to the mouth it averages about half a foot. The volume of the river at Tuscumbia has been estimated [*228, vol. xvii*] to be 300 cub. ft. per second, during low water. It is subject to very rapid changes of volume, however, and has risen as much as 39 ft. above low-water mark. Like almost all of the streams of the state, it consists of a channel of pools, alternating with shoals or gravel bars which are laid nearly bare in times of drouth. Opportunities for the development of water powers are afforded by these shoals at a number of points.

As is plainly indicated on the map, the upland meanders of the Osage are remarkably developed. From the mouth to the point where the Osage enters the district in Benton county, the distance, following the general course of the river, is about 90 miles, while following the meanders it is twice this, or 181 miles. The details of these meanders

are the same as in the southwest. The precipitous bluff of the down-stream side and the gradual slope of the up-stream side are especially well shown.

Tributaries of the Osage.—The principal tributaries of the Osage are on the south side of that stream. In fact, the shortness and insignificance of the northern affluents is to be specially remarked; the only considerable one is Grand river above Warsaw, and this flows more from the west than from the north. On the south side we have, as large tributaries, the Pomme de Terre, Niangua, Auglaize, Tavern creek, and their forks.

The features of these streams are similar to those of the Osage. They all have upland meanders—their amplitudes being proportional to the size of the stream. The flood plains are of considerable width, especially near the Osage. The declivities are generally great, and these streams are further fed by large springs, which, together, present conditions favorable for good and durable water powers.

Springs.—Bryce's spring, on the Niangua, which is considered the largest, is claimed to yield 8000 cubic feet per minute [*228, vol. xvii, p. 364*]. Gunter's spring, also flowing into a fork of the Niangua, is another with an approximate flow of 4000 cubic feet per minute [*3*]. A mill is kept running from this spring, which utilizes only a small part of the water. The views on the opposite page illustrate some of the features of this locality. There is much of natural beauty in the country here, and the clear water, large limestone caves, natural bridges, etc., are features of interest. All these springs issue from openings in the limestone country rock, many of which enlarge into caves; they are really outbursting subterranean streams, which are powerful agents of under-ground erosion. Did time permit, it would be interesting to describe and discuss other features of these springs and caves; we hope to have opportunity to do this in some later publication.

The Gasconade drainage occupies only a small patch in the southeastern corner of the district. This river has all of the features of the Osage. Particularly to be noted here, also, are the strong meanders and the shortness of the northern tributaries. The distance in a straight line between the points of entrance into and outflow from the district is 30 miles; following the meanders, the distance is 69 miles. The St. Louis & San Francisco railway here follows the divide between the Osage and Gasconade. At one point, as can be seen on the map, the

VIEWS AT GUNTER'S SPRING.

head-waters of an Osage tributary, Tavern creek, reach up to within a mile of the channel of the Gasconade.

Soils.—The northern, and especially the northwestern part of this district, is characterized by rich prairie soils. This portion is just on the margin of the glacial deposits, and possibly some part of these extend into it. Most of the soils are, however, residuary. The prairie soils extend southward to the breaks of the Osage. Over the plateau country good residuary soils are found on the broader hill-tops, and in the troughs of the valleys. The narrower ridges are chert-covered and rocky, and are hardly arable land. Along the Osage, Gasconade and larger tributaries, alluvial loams, consisting of transported material, are spread over the bottom lands; these lands are subject to overflow in times of high water, often with disastrous results.

Forestry.—The forestry of this district is also similar to that of the southwest. Over the prairie country the growth of timber is somewhat sparse; over the plateau country it is thicker, though the trees are not very large. The growth of oak is, however, fair, though not extraordinary. Post and white oaks supply a large tie business. These ties are hauled from all parts of the country for miles, and are dumped into the Osage or its tributaries, and floated thence to the railroad at Warsaw or Bagnell, or to Osage City, at its mouth. Along the river bluffs, these dumping places, or chutes, are conspicuously marked by strips, extending from the summit to the water's edge, 100 or more feet wide, destitute of vegetation or soil, down which the ties are slid.

ORIGIN AND FORMATION OF TOPOGRAPHIC FEATURES.

Before leaving this subject, it will be interesting and profitable to inquire into the history, and to attempt to explain the reasons for the features of the topography which we have thus far briefly described. This has been done in part already, at least by inference. Much has, however, not been touched upon. The features which seem to us most remarkable and worthy of special attention here are: 1) the plains of the prairies and plateaus; 2) the meandering valleys of the streams; 3) the positions of the divides between the principal streams.

In order to determine the origin of these features, it is necessary to consider the geologic history and structure of the region. Certain facts of geology have already been given in the preceding pages, and the whole subject is fully discussed in the next chapter, to which reference should be made for any details introduced in the present connection.

History of drainage.—The beginning of the sculpturing of the present land forms in Missouri, we assign to the time of the post-Carboniferous uplift, when the newly deposited Coal Measure rocks were brought above the surface. Then, all of Missouri became dry land, excepting the Mississippi embayment of the extreme southeast.

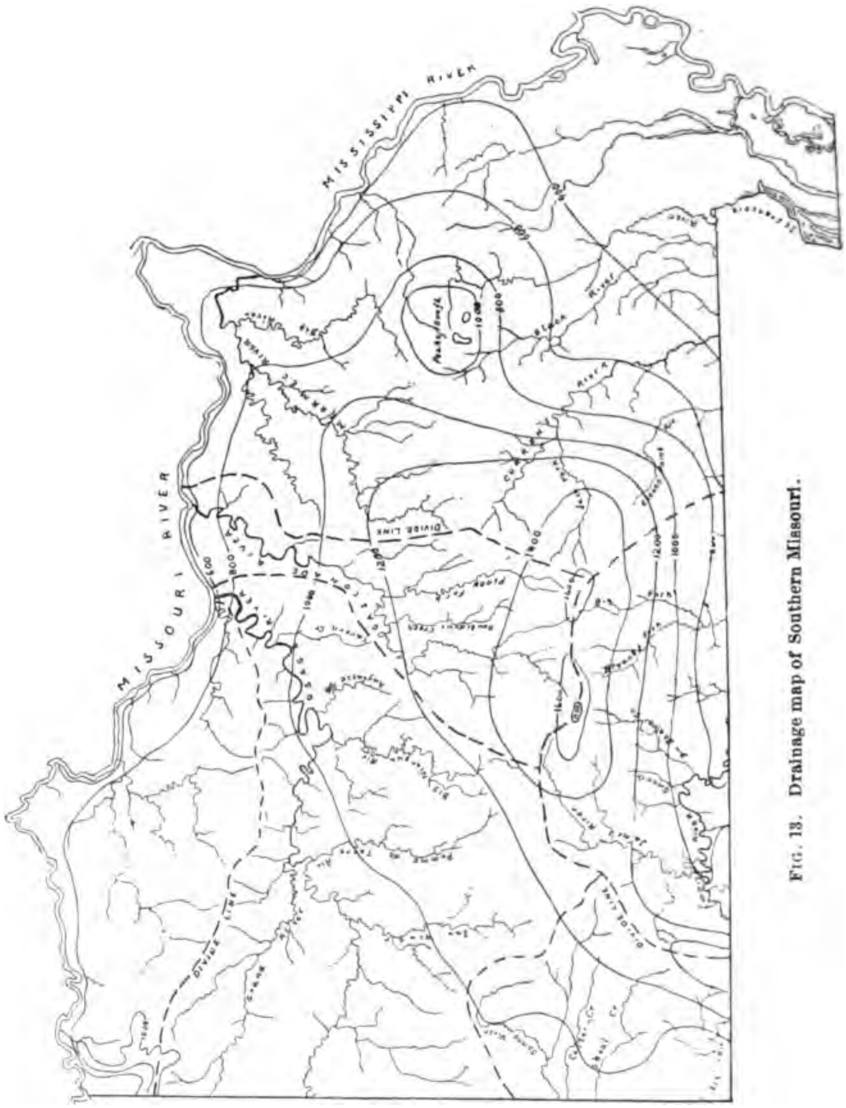


FIG. 13. Drainage map of Southern Missouri.

From the distribution of the then surrounding seas, from the thinness of any Coal Measure deposits which may have extended over the

Ozarks, and, from our knowledge that this was an area of uplift since Archean times, we are warranted in concluding that the Ozark area of southern Missouri was the most elevated portion of the state during this period. The first, or the "constructional" surface must have been dome-shaped, and the streams must, from the beginning, have flowed radially from the center, somewhat as today, as shown on the opposite map. This dome was, moreover, a quaquaversal arch, composed of strata of limestone, sandstone and chert, dipping conformably with the surface.

The probabilities are that the main drainage lines of the state were determined by constructional features, and became defined immediately after this uplift. The Mississippi river we regard as a product of the Ozark, the Cincinnati and the Wisconsin-Minnesota uplifts combined; the lower Missouri was similarly the result of the Ozark and Wisconsin-Minnesota uplifts; White river established itself between the Ozark uplift on the north and the Boston mountain monocline on the south. Spring river and the upper Missouri could not have been defined until later, until after the post-Mesozoic uplift of the Rocky mountains. Up to that time, the drainage of western Missouri must have been westward into the Mesozoic seas of Kansas.

This post-Mesozoic uplift shifted the divide from within the state border to the far west. It was probably accompanied by some flexing, which may have assisted, at least, in locating Spring river and the Missouri river north of Kansas City. With this uplift, a great volume of water must have been thrown into the Missouri channel from the western country, much augmenting the importance and duties of that stream. It is probable that the drainage of the Ozark area was itself little affected by this post-Mesozoic uplift to the west.

The original rise of the Ozark dome was not accompanied by flexing or by specially great disturbance of the strata, and the surface was probably a plain from the beginning. To what extent this plain remained unbroken is dependent upon the length of time occupied by the uplifting. Perhaps denudation and erosion progressed during this process, and perhaps by the time Missouri was entirely above water the surface was already [illegible]. It is not probable, however, that the degradation was very great. More likely, the surface was still comparatively smooth up to the time all of the state had emerged. This primeval surface we may term the Original plain.

Origin of the Plains.—What is the origin of the plains of southern Missouri, as represented in the prairie country and in the uplands of the plateau country thus far described? Are they merely uneroded portions of the original plain? We think not. This allows too little for the forces of erosion to have accomplished during the long time which has elapsed since the end of the Coal Measure epoch. Further, hills exist, at points, well above the general level of the plain, sometimes rising abruptly, mesa-like.* These are composed of strata belonging geologically above those of the surrounding plain. They are, hence, outliers or remnants of strata which have been removed by erosion from over the present surface.

Do these plains represent a past base-leveled condition of the country, a peneplain formed, perhaps, long after the first uplift, sufficiently long for all of the original surface to have been eroded down to a lower plain, which was later re-elevated and re-eroded to the present condition?† This idea is not without support, and deserves further consideration; but other reasons prevent us from accepting it, at least for the present. The principal of these reasons are: 1) there is lack of positive evidence of such a past base-leveled condition; 2) the hypothesis requires a precise adjustment and correspondence in dates of earth movements and stages of degradation which we do not see good reason for; 3) it requires an extension of the base-leveled condition which seems extreme; 4) we think the phenomena more readily explained by other hypotheses.

The hypothesis which we advance is that these prairie and plateau plains are primarily due to the fact that the slope of the surfaces has always been and continues slight, as is indicated on the contoured map on page 320. Consequently, the flow of the streams has been so sluggish that general atmospheric degradation has nearly kept pace with the corrasion of the streams and the formation of the valleys. As a result, the whole surface has been denuded simultaneously. This condition is attributable, first, of course, to the gentleness of the original constructional slope; the horizontality of the stratification has helped to perpetuate it. The streams were unable to select soft rocks for channel cutting, as in a flexed region, and have had to slowly cut their way down through flat layers. Much of the area of the plains is

* No such hills exist within the area of the mining districts defined, but they are well developed along the western border of Bates county, not far north of Jasper county.

† This idea is in harmony with an interpretation of other phenomena advanced by Prof. Wm. M. Davis, of Harvard university, which will be referred to later.

underlain by Coal Measure rocks, which are readily acted upon by sub-aerial agents of erosion. Wherever the local declivity has been great, the streams have cut their valleys rapidly, have sunk below the general level, and their tributaries have dissected the adjacent country. In this way have arisen the plateau areas of White and Osage rivers.

Secondarily, as a factor in the production of these surfaces, it is probable that, where streams have corraded so slowly, broad flood plains have been developed at different levels at different times. Thus, many flat stretches, which may now be removed from the formative streams, are, perhaps, to be considered as of the nature of terraces marking the flood plains of a past stage of erosion.

Finally, we must recognize as an agent in producing these results, the Tertiary or early Pleistocene submergence or overflow, which much of the prairie country of the western part of the state appears to have been subjected to. This is discussed in chapter X; the evidence rests principally upon the existence of chert gravel over the country adjacent to the larger streams. During this period of overflow, much must have been done in the way of filling the inequalities of the surface with clays and gravels, resulting in the production of plains.

River Meanders.—The peculiar upland meanders of White, Osage, Big, Gasconade and other rivers of southern Missouri have already been described in a general way. The most remarkable fact about these sinuosities is that they are not in flood plains, but are around spurs of high upland country. This is well illustrated in the following cut, as are other details, which we wiil now proceed to consider.

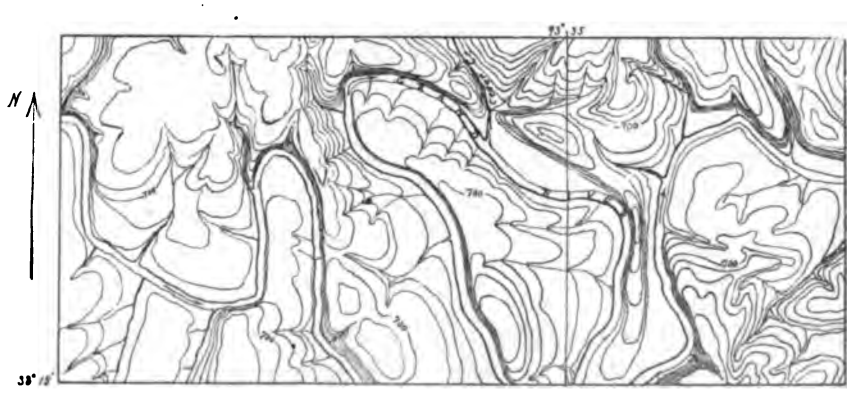


FIG. 14 Meanders of Grand river, a tributary of the Osage.
Scale, 1 mile to 1 inch. Contour interval 20 ft.

It is to be particularly noted that the channel of the stream constantly hugs the hills on the side impinged by the current, and here we find precipitous bluffs maintained. On the "lee" side of the stream are such alluvial plains as exist, whence the slopes are normally gentle to the summits. The points or promontories of the uplands, which are at times nearly surrounded by the loops of the river, slope somewhat gradually toward their ends, and do not terminate in bluffs. These features are of general occurrence along all of the streams referred to. They cannot be brought out on maps of a small scale; but on maps of one mile to the inch, with 20 ft. contours, recently constructed by the Geological Survey, they are clearly shown.

These meanders, more particularly of the Osage, have been the subject of some discussion between Prof. Wm. M. Davis and the writer [*59*, *345*]. Prof. Davis' explanation is that they have been developed, by elevation and corrasion, from flood plain meanders of the stream, which originated during a past base-leveled condition of the country. This is in harmony with the base-level hypothesis of the prairie plains. But here, as there, base-leveling does not seem necessary.

If we take the case of a stream with a slightly sinuous course and of considerable declivity, moderately incised in a nearly flat, or even in an undulating country of horizontal strata (conditions such as would exist with a newly emerged land surface) we can understand that meanders will tend to develop somewhat as they do in the alluvial plain of a stream which has reached base-level. Where the current impinges, sapping will increase the convexity, and the sinuosities will become more pronounced. Inasmuch, however, as the declivity of the stream is great, corrasion is still active, and the channel sinks vertically at the same time that it moves laterally, the action thus differing from that of a stream in a base-leveled alluvial plain. As a natural result of this process, we can see how the stream will eventually shape for itself a tortuous and steep-sided valley, with very narrow flood plains, until the channel has reached base-level, when corrasion will cease and lateral degradation will increase; then, swinging from bluff to bluff in a secondary system of sinuosities, the stream will sap its bordering hills and widen its flood plains.

Expressed in general terms, then, the view here advanced is: that under certain conditions of declivity and stratigraphy, streams will acquire meandering courses, irrespective of whether the country be a flat plain or not, and irrespective of whether the original lines of flow

be decidedly sinuous or only gently curving; the radius of developed meanders will, of course, in any case be proportional to the volume of the river.

This conclusion seems to follow logically from the premises that all rivers exert a sapping as well as a corrading action, or, in other words, that they tend to erode laterally as well as vertically. To produce these special results, it is necessary that the declivity be not so great that lateral wear becomes altogether insignificant as compared with vertical wear; or that stratigraphic conditions be not such as to entirely thwart these tendencies of running water. In a strongly flexed region, for instance, the drainage is largely controlled by the attitude of the rocks. A country of horizontal strata of moderate resistance, such as those of the Ozark plateau, is particularly favorable to the development of a swinging course. Where soft and hard beds, like shale or limestones and cherts, alternate, we can readily conceive how a stream of comparatively rapid fall may move or expand its meanders considerably while cutting only a slight depth through underlying resistant beds.

Mr. Marbut has called the attention of the writer to the fact that such meanders do not characterize all of the streams of the region, and that they appear to be excluded from the prairie country of Carboniferous rocks, and to be confined to the Lower Silurian magnesian limestones. He has suggested that the cause lay in the character of the rocks. To us it appears that it lies, rather, in the fact that the declivities of these streams are less; they are nearer base-level, whether this be merely temporary or not, and, if ever such prominences existed, they have been worn away to produce the present alluvial plains. Further, along small streams, where the declivities are very great, we do not find, nor do we expect to find, such meanders. Here corrasion sinks the channel too rapidly for lateral wear to be great.

Positions of Divides.—A peculiar fact concerning the divides between some of the larger streams of southern Missouri is the inequality of the width of the drainage area of the two sides; or, otherwise expressed, the differences between the lengths of the tributaries on the north sides and those on the south sides of such streams. This is notably the case with the divide between White river and the Osage, between the Gasconade and the Osage, and between the Osage and the Missouri rivers. With all of these, the tributaries flowing southward are much shorter than those flowing northward; in fact, along

the Gasconade the divide on the northern side runs along the very bluffs overhanging that stream.

The explanation of this remarkable feature is to be found, we think, in the original, constructional, northward slope of the surface, and corresponding dip of the rocks. It was, probably, much more pronounced in the early history of the drainage. The tendency has been to equalize the area by a shifting of the divides, and this tendency is still maintained. It will continue for some time, but we must ultimately look for the reverse of the present conditions.

The reason for this will be best understood by a study of the following series of diagrams. If we consider A to represent a cross-section of the country at the time these streams first occupied their positions, we see that the surface was then sloping gradually northward from the crest of the Ozark to the Missouri river, and southward to White river.

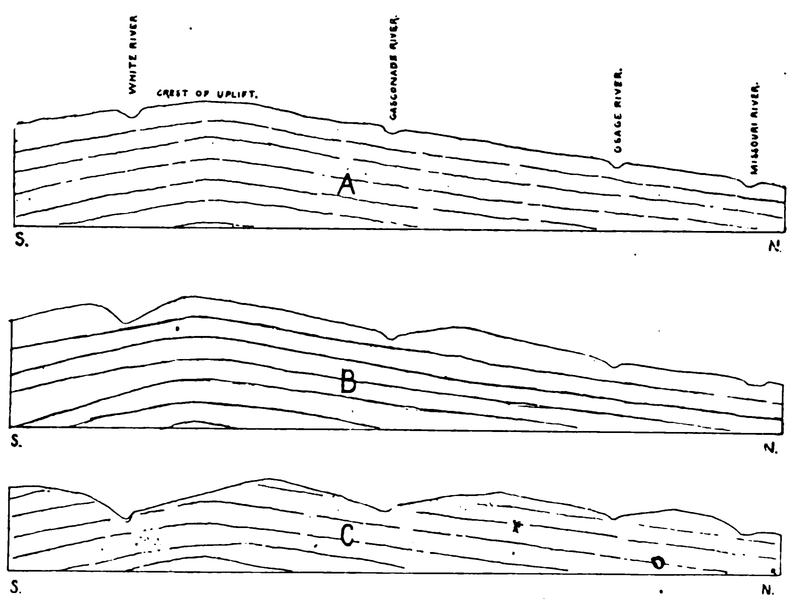


FIG. 15. Diagram illustrating shifting of divides.

Under these conditions, the depression representing the White river trough, however originating, would have affluents only from the north, while those representing the Gasconade, Osage and Missouri rivers would receive such only from the south. As these streams became "consequent" and lowered their channels, tributaries on the opposite sides would begin to etch back the divide lines. The longer the period, the farther back would these tributaries extend, passing through stage

B to the stage C. The former (B) represents approximately the present condition. As White river is at a lower level than the Gasconade or Osage rivers, it is to be expected that the divide between it and these streams will continue to migrate northward until the declivity on each side becomes the same. It will then be in a position of equilibrium, though unstable. This is true in a general way, though stratigraphic and other conditions exert modifying influences.

We will conclude this chapter on the topography of southwestern Missouri with these remarks, though, confessedly, somewhat reluctantly. The ideas presented have been more in the nature of suggestions than established theories; it is to be hoped that they will lead others to study the ground more thoroughly and to inquire into causes. The field is a profitable one for future work, and there is much in it that needs elaborating. The topography of Missouri can well be made a subject of a separate monograph.

CHAPTER IX.

GENERAL GEOLOGY.

THE ARCHEAN.—THE ALGONKIAN.—THE SILURIAN.—THE DEVONIAN.

The formations of the three mining districts are: the Archean, the Algonkian, the Silurian (with possibly some Cambrian), the Devonian, the Lower Carboniferous and the Coal Measures; above these, in places, are certain unconsolidated beds of probable Tertiary age. These formations make up all of southern Missouri, and the stratigraphic problems of the region are the problems of the districts. Certain of these problems will receive consideration here, but we shall not undertake a full discussion of them. More work is needed and more detail is to be acquired before this should be attempted. We shall endeavor to make this chapter, primarily, a description of actual occurences and conditions in the respective districts, introducing in detail only such facts and conclusions as are new, and are contributions of our knowledge of the localities.

THE ARCHEAN.

The Archean rocks are confined entirely to the Southeastern district. They consist principally of the acidic eruptives, granites and porphyries; these are traversed in places by dikes of basic eruptives, intrusive in the former and consisting mostly of diabase. A special report on these rocks has been prepared by Prof. Haworth, and is now awaiting publication. Moreover, they have been, in part, quite fully described in a recently issued report on the Iron Mountain sheet; and in the description of the Mine La Motte estate, in a later chapter of this report, much additional detail is given. Hence, in this connection, only a brief statement will be presented, for which we are largely indebted to Mr. Haworth's Iron Mountain report.

Distribution.—The exposed areas of these rocks are clearly shown on the map. They occur in hills of the St. Francois mountains, surrounded by Silurian rocks in the valleys. The larger portion of the

exposures represented on the map consist of porphyry; the granite is confined almost exclusively to the portion lying east of the line between ranges 4 and 5 E., and north of the parallel running through the Einstein mines.

Dikes are not very abundant, and show themselves at the surface at scattered points, covering small patches, too small to be represented on the map.

Lithology.—The porphyries are generally red or brown, and are composed principally of quartz and feldspar, with small grains of iron oxide scattered through them. The texture is fine-grained and homogeneous, and, under the microscope, is holocrystalline; larger porphyritic crystals of quartz or feldspar occur, scattered through the ground mass. The wavy lines, known as flowage structure, are also presented. The rock is frequently brecciated, the fragments themselves being composed of porphyry.

The granites are generally of a pink color. The constituent minerals are principally quartz and feldspar; in a few places black mica occurs, but it is not evenly disseminated; hornblende is very rarely found. In texture they frequently approach the porphyritic, and the feldspar sometimes occurs as a ground mass, in which quartz crystals are imbedded. In other cases, the constituent crystals of quartz and feldspar are clearly separable, and are in nearly equal proportions.

Regarding the relations of the granite and porphyry, the conclusion has been reached by Mr. Haworth that they were "formed from the same or similar molten magmas, and that their differences in texture are probably due to their solidifying under different physical conditions, and, secondarily, to a slight lack of homogeneity in the magmas."

Diabase is usually found in well-marked dikes or bosses. The dikes vary in width from less than an inch to over 150 feet. They usually trend NE.-SW., with nearly vertical walls. The rock is dark green in color, sometimes nearly black. The principal minerals are triclinic feldspar, augite and olivine, with accessories. In texture, these rocks vary from coarsely granular to very compact and glassy.

THE ALGONKIAN.

The Algonkian rocks are confined essentially to a limited patch at the top of Pilot Knob, in the Southeastern district. This is a remnant of a former extensive mass. They are of little importance to the present report, and hence will be passed by with only a brief reference.

These rocks have been quite fully described in the recently issued Iron Mountain sheet report and in earlier publications of this Survey. They consist principally of conglomerates and slates, capping the knob and aggregating about 200 feet thick, including a bed of specular iron ore. The slates show bedding structure very perfectly in places, though elsewhere it is absent. The conglomerate consists of fragments of porphyry included in a fine, felsitic matrix, containing varying amounts of hematite intimately intermixed.

THE SILURIAN.

The rocks of the Silurian system are represented in each of the three districts. They are the surface rocks over the largest portion of the Southeastern district and over almost the entire Central district, and in these areas they contain all the important lead and zinc deposits. The aggregate thickness of the rocks is probably not far short of 2000 feet, though it is doubtful whether this thickness is represented at any one place.*

At the base of the Silurian rocks are the Archean crystallines, and, possibly, the Algonkian, under now covered areas. Rocks that have been thought to be Cambrian occur near the base at some localities, but the evidence is opposed to this conclusion. The upper limits vary because of unconformity; they may be marked by Devonian, Lower Carboniferous or even Coal Measure strata.

Stratigraphic range.—The rocks range from the Lower Silurian to the Lower Helderberg of the Upper Silurian. Of importance to the mining districts is, however, only the Lower Silurian, and of this the

* In the St. Louis insane asylum well, the rocks assigned by Broadhead to the Trenton, Black River and Bird's Eye limestone are 421 feet thick, and those assigned to the Ozark stage 1499 feet, aggregating 1920 feet. Near Sullivan, in Franklin county, a drill-hole has been sunk, in which granite was encountered at 1100 feet. This hole was started, however, well below the top of the Ozark stage. At Jefferson City, a drill-hole beginning below the Saccharoidal or Roubidoux sandstone, penetrated 1160 feet without reaching crystalline rock. At Carthage, a hole struck porphyry at a depth of about 2000 feet. Of this, all below 400 or 500 feet are probably members of the Ozark series.

rocks belonging to what is known as the Ozark stage are almost the only ones encountered. The following descriptions apply principally to these. In the subjoined table a provisional classification is offered, which will be followed in the descriptions.

TABLE OF LOWER SILURIAN FORMATIONS OF THE MINING DISTRICTS.

<table>
<tr><th></th><th>Southwestern.</th><th colspan="2">Southeastern.</th><th colspan="2">Central.</th></tr>
<tr><td rowspan="3">Trenton.</td><td rowspan="3">Absent.</td><td colspan="2">Hudson river shale.</td><td colspan="2" rowspan="3">Absent.</td></tr>
<tr><td colspan="2">Receptaculites limestone.</td></tr>
<tr><td colspan="2">Trenton limestone.</td></tr>
<tr><td rowspan="7">Ozark.</td><td rowspan="7">White river limestone, including several beds of sandstone.</td><td colspan="2">Joachim limestone.</td><td colspan="2" rowspan="2">Roubidoux or Saccharoidal sandstone.</td></tr>
<tr><td colspan="2">Crystal City sandstone.</td></tr>
<tr><td rowspan="2">St. Francois limestone.</td><td>Potosi limestone.</td><td rowspan="5">Gasconade limestone.</td><td>Jefferson City limestone.</td></tr>
<tr><td>St. Joseph limestone.</td><td>Moreau sandstone.</td></tr>
<tr><td colspan="2">LaMotte sandstone.</td><td>Osage limestone.</td></tr>
<tr><td colspan="2" rowspan="2">Iron Mountain conglomerate.</td><td>Cole Camp sandstone.</td></tr>
<tr><td>Proctor limestone.</td></tr>
</table>

Lithology.--By far the greater portion of the Silurian rocks are magnesian limestones; next in quantity are the sandstones and cherts, and last, are the shales and conglomerates.

Limestones.—In texture, the limestones vary from very fine, like a slate or shale, to coarsely granular, composed of a mass of small crystals. They may be dense and homogeneous, or pitted, porous and even vesicular; in such latter the cavities or pores are generally lined with minute dolomite crystals, and sometimes with quartz and other minerals.

Some varieties develop a very open structure on weathering, due to inequalities in composition. This is particularly observable in some of the Trenton beds, but it also occurs in those of the Ozark series. Such rock has almost the appearance of a tufa. In instances, a brecciated structure is observable, probably due to some movement, or to a partial solution of the rock along certain lines, followed by breaking down and recementing of the fragments. Such brecciation is represented in the railway cut above Mansfield, and at other points. These limestones sometimes occur in thin and even shaly layers, but are generally in massive beds, often 15 and 20 ft. thick.

The color is generally light or dark gray on fresh fracture, and a yellowish tinge is often acquired on exposure. Some beds of red, pink and brown colors are classed as marbles.

The more crystalline and granular rocks are generally very tough, and difficult to break, while the more earthy and finer textured varieties are often fragile.

In composition, these are magnesian limestones, containing a large percentage of magnesia, though generally with less than a theoretical dolomite. In some, crystalline masses of calcite are included, indicating an excess of lime. The opposite table illustrates the ranges in composition.

This table shows that some beds contain very little magnesia, noticeably those which are classed as marbles. Others are high in silica and alumina; in some of these, quartz grains were quite noticeable to the eye, and often make up a large part of the rock, such that it grades into sandstone; similarly, with regard to alumina, a transition into shale can be traced. In some beds, particularly in the southeast, a large percentage of chlorite is noticeable, sufficient to give the rock a distinct green color; such rock has also been observed near Protem, in Taney county. One of the best defined varieties of the magnesian limestone is what is known as cotton rock; this is of a white or cream color, very fine grained, homogeneous and dense texture and somewhat earthy in appearance. It is always very evenly bedded, in layers a few inches to 2 ft. thick, constituting strata 20 to 30 ft. thick; its fracture is semi-conchoidal; it is easily quarried, and is much used for building purposes, but often becomes discolored on exposure. It is most abundant in the Central and Southwestern districts. The more granular limestones are tougher and harder to work; but they are more durable, and some are exceedingly strong.

VESICULAR MAGNESIAN LIMESTONE.

From photograph by E. M. Shepard.

TABLE OF ANALYSES OF LOWER SILURIAN LIMESTONES.

Number	Locality.	Silica	Combined oxides	Calcium Carbonate	Magnesian Carbonate	Total	Analyst	Survey Anal. No.	Catalogue No	Remarks.
1	Cole county, Jefferson City	8.62	12.81	41 84	37 44	100 20	Robertson	382		"Cotton rock," soft, earthy lustre.
2	Crawford county	1.94	1.46	95 23	1 81	99 94	"	407		Marble, dark brown, nearly black, hard, compact, crystalline.
3	Franklin county	6.14	1.27	52 48	39.19	99.08	"	375	3800	Cherty limestone, magnesian, rather compact.
4	Iron county	4 67	2 48	89.07	3.75	99 97	"	410		Marble, reddish, crystalline, hard.
5	"	2.96		53 28	40.81	97 05	Potter & Riggs			Pilot Knob [School of Mines Quarterly, vol ix].
6	Madison county	1 27		55 20	40 90	97.37	Neill			Mine LaMotte [School of Mines Quarterly, vol. ix].
7	Morgan county	14 71	1.68	46.63	36.06	99 89	Chauvenet			[Report Mo Geol. Sur., 1873, p. 519]
8	St. Francois county, Desloge	3.26	1 76	55 41	39 54	99.97	Robertson	354	3678	Hard, compact dolomite, arenaceous looking.
9	" " Valle	1.16	1 16	71 38	26 12	99 82	"	356	3684	Hard, compact dolomite.
10	" " Doe Run	20 04	5.34	49 27	17.61	92 28	"	359	3676	Hard, compact, sandy dolomite, resembling sandstone, earthy lustre.
11	" " "	55.95	4.96	23 22	15.58	99.71	"	371	3675	Calcareous sandstone.
12	" " Bonne Terre			50.00	43 90	93 90	Monell			Desloge Company, tailings [School of Mines Quarterly, vol ix].
13	" " "	3 77	6 88	60.33	31.75	102.75	"			St Joe Company, surface [School of Mines Quarterly, vol. ix].
14	St. Louis county	.35 to12.15	.30 to 1 05	82.55 to98 60	.27 to 9 27		Woodward			Range of ten samples. Trenton limestone from St Louis county, Bul. 3 Mo Geol Sur., p 78.
15	"	12.35	1.10	48.75	37.09		"			"First" magnesian limestone, railway cut, Glencoe, Bul. 3, p. 78.
16	Washington county, Poverty Flat	1.15	3.00	53 50	42.30	99 95	Robertson	403		Hard, compact, drab.
17	Wright county, Mansfield	2 30	2.73	53.72	40.79	99.54	"	366	2869	Hard, buffish, drab magnesian limestone, arenaceous looking, fine grained, crystalline. Leadhill near Mansfield.
18	" "	20 22	4 34	41.44	34.69	100 69	"	372	2870	Very clayey, earthy lustre, "cotton rock."

As to the origin of the dolomites, no original investigations have been conducted. Observations lead one to believe that they were in part originally deposited as dolomite, and in part have become so through secondary alteration. In support of the first, we would refer the reader to a large number of analyses of consecutive layers of St. Louis limestones, published on pages 76 and 77 of Bulletin No. 3 of the Missouri Geological Survey. From these it will be seen that highly magnesian layers alternate with others almost entirely destitute of that material. It is difficult to understand how any secondary process of alteration can be so sharply limited. On the other hand, the general magnesian character of the great mass of Silurian limestones within the mining districts, their porous structure and other phenomena, more than suggest the result of secondary action.

Regarding the origin of the marbles which are found associated with these limestones, we have already expressed the idea [*249, p. 30*] that the low percentage of magnesia may have something to do with it; the idea is further supported by the absence of magnesia in the Crawford county specimen of the above table.

Cherts.—Cherts are not so abundant as limestone, but they are, perhaps, equally conspicuous, because of their comparative indestructibility. Large residuary accumulations are found wherever such cherts are present. They are distributed throughout the whole Silurian section, though apparently less abundant in the lower strata, at least as existing in St. Francois county, where the lower 500 ft. or more are nearly destitute of chert. In the Trenton limestone, chert is also not abundant, though it is found here in small isolated lenses and in thin layers, running parallel to the stratification.

Chert occurs in beds sometimes as much as 6 ft. thick, though generally the beds are thinner and are frequently mere lenticular layers. It also occurs in nodules and in irregularly-shaped masses in limestone. The beds of chert alternate with limestone beds. Sometimes it is intimately mixed with the limestone.

The texture of the chert is often smooth and glassy, very hard, and breaking with a sharp semi-conchoidal fracture; it is sometimes oolitic, sometimes dense or granular, friable and soft, like sandstone of a very fine texture. It is also porous and vesicular to tufaceous; it is sometimes brecciated—the fragments being cemented by amorphous silica or lime. Several varieties are illustrated in the opposite plate.

LOWER CARBONIFEROUS AND SILURIAN CHERTS.

No. 1. POROUS CHERT.
No. 2. DRUSY QUARTZ OR "MINERAL BLOSSOM."
No. 3. FOSSILIFEROUS LOWER SILURIAN CHERT.
No. 4. FOSSILIFEROUS (CRINOIDAL) LOWER CARBONIFEROUS CHERT.
No. 5. "INTERLOCKING" CHERT AND LIMESTONE.

The color is generally dark-gray or bluish, sub-translucent, also white to yellow and red, of an earthy luster.

In composition, these cherts, when not visibly mixed with foreign materials, are almost pure silica, mostly of the chalcedonic variety; sometimes, however, more or less lime is diffused through them. Visible impurities, such as sand, limestone, shale, etc., are frequently found enclosed. The composition of the Lower Silurian and other cherts is shown in the table of analyses introduced in Dr. Hovey's paper on Missouri cherts, which forms appendix A of this report.

Where chert occurs in thick beds, these are noticeably cellular, and have often a brecciated appearance. Their contacts with the under and overlying limestone beds are also more or less uneven. The thinner layers are generally more compact; they, as well as the chert in the nodular form, have more regular outlines. Sometimes, however, these outlines are very irregular, the chert apparently filling cavities and crevices of the limestone both above and below. This is well illustrated in the adjoining sketch, made from an exposure at Tuscumbia, in Miller county.

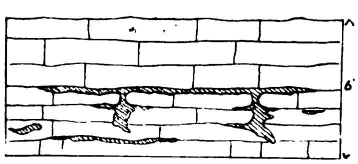


FIG. 16. Chert in limestone at Tuscumbia.

Many of the white cherts decompose on exposure and become soft and friable-like chalk; this is doubtless due in some cases to the removal of lime disseminated through the rock, for some of the very densest and hardest cherts effervesce with acids. Sometimes, in these chalky cherts, there are specks and small patches of a black, flinty-looking chert, which is doubtless formed by secondary concretionary action.

In Southeastern Missouri, there is found at some localities in great quantities a drusy quartz, known as "moory flint" and as "mineral blossom." It is illustrated in the plate. This form of silica deserves consideration here. It occurs in pipes and irregular sheets, filling or lining small cavities and crevices in the magnesian limestone. Frequently, in particularly decomposed outcrops, the chert covers the exposed surfaces of the limestone. This chert is composed essentially of amorphous silica in thin, chalcedonic layers. It is generally coated uniformly with minute quartz crystals. Occasionally, quartz crystals cover the surfaces or fill crevices and cavities of other varieties of chert; but they are nowhere so abundant as upon this drusy quartz. Other forms of vesicular cherts exist, but they are simply masses of

ordinary chert filled with small cavities, the larger ones being also often lined with quartz crystals.

An extremely interesting variety of chert, quite abundant in these rocks, is an oolitic chert, composed of minute spherical grains of silica. Sometimes the whole mass of the rock is thus constituted; sometimes the structure is confined to bands which alternate with dense layers; sometimes, the oolitic chert encloses brecciated-like fragments of white, dense chert, and is then evidently of later formation. The spherules are generally smaller than a pin's head, are composed of silica, have a concentric structure, and sometimes a central cavity. They are held generally in a matrix of amorphous silica, though sometimes the matrix appears to be calcareous. A removal of the little spheres frequently gives a pitted appearance to the rock. Sometimes, grains of sand are cemented together by similar amorphous silica, producing an oolitic-looking rock, which it is difficult to know whether to classify as a quartzite or a chert.

Rocks formed of a mixture of chert and limestone are of common occurrence, and are of much interest. The two substances sometimes exist in the shape of small, lenticular sheets, closely interleaved, and sometimes the masses are of irregular shapes and interlock, somewhat as is illustrated in figure 17. Sometimes, the mixture is very intimate and the limestone can only be separated by etching with acid.

Fig. 17. Interlocking of chert and limestone.

When fossils are observable, the chert generally exists as a cast filling the original cavities; but, in rare cases, it is seen to have replaced the shell itself.

In nodular and lens-shaped masses, the concentric structure is often developed, and distinct banding is very common. The adjoining sketch, made in the Sophia cut, at the Frumet mine, illustrates one such condition. In a few cases specimens have beeen seen in which thin bands of chert and sandstone alternate with each other.

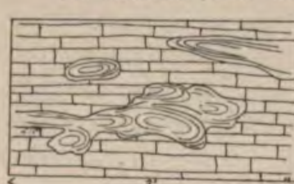


FIG. 18. Concentric structure of chert.

A quite complete microscopic and chemical study of these cherts has been made in connection with this report. The results are presented in appendix A, together with those of the Carboniferous cherts.

Sandstones.—The sandstones of the Lower Silurian occur in strata from 1 to 50 ft. thick; they are found in thin, flaggy layers, or in heavy, massive beds; the latter are generally false bedded, and exhibit an irregular contact line with the underlying formation.

The most important sandstones are friable and soft; some are perfectly white, and contain over 99% of silica; others, especially near the base of the series, are ferruginous, coarsely grained grits, with admixtures of porphyry, or feldspar when near the Archean area. Some of the sandstones are decidedly calcareous and grade into limestone.

In southern Missouri, thin beds of well-indurated quartzite occur; these are often of vitreous luster, and require careful observation to separate them from the cherts. Even in some soft, friable sandstones, patches of quartzite are found arising from segregating action.

Some sandstones contain visible fragments and specks of chert, derived from underlying rocks. This is an interesting fact, indicating unconformity, and showing that the cherts were already consolidated at the early date of the deposition of this sandstone. The sandstones are normally of a gray or bluish color, but white, red, yellow and even green varieties are found. They are all non-micaceous, and in this respect differ from Lower Coal Measure sandstone.

Shales.—Shales are not very abundant, and occur principally among the lower strata of the series; they are drab, blue or greenish, never black; are crystalline, calcareous, arenaceous, and grade into shaly limestone. The individual strata seldom exceed 10 to 15 ft. in thickness, and these do not seem to be persistent.

Conglomerates.—The only conglomerates of the system are those found around the Archean hills. They are composed of boulders and pebbles of granite and porphyry, in a clay or limestone matrix. At the Doe Run mine, lead ores are mined from such conglomerates, as will be described later. Elsewhere they have no connection with the ore deposits.

THE SILURIAN OF THE SOUTHWESTERN DISTRICT.

The total thickness of the Silurian rocks exposed within the district limits is in the vicinity of 500 feet. These are apparently all Lower Silurian, and all members of the Ozark stage. The Trenton and overlying Lower and Upper Silurian beds are absent. A subdi-

vision of the section will not be attempted. The fauna is scant, and not sufficiently studied to attempt separation upon paleontological grounds; no distinct stratigraphic breaks are recognized, and, though there are lithologic differences, these have not been demonstrated to be persistent, nor have they been correlated with sufficient care for a division into sub-stages to be advisable.

Stratigraphic Limits.—The upper limits of the Silurian are here defined by the base of the crinoidal limestones of the Lower Carboniferous, or by a bed of sandstone, generally only a foot or so thick, though locally expanding to greater dimensions. In the extreme western portion, a stratum of black shales of probably Devonian age marks the limit.

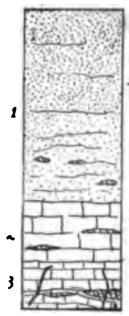
Corresponding to this variation in the upper limiting beds, the uppermost member of the series is not the same in different sections. This is due to the fact that the contact is unconformable, and a period of erosion intervened.

The basal limits of the system are not reached within the area.

Distribution.—The distribution of these rocks is so clearly shown on the district map, that little need be said here. The outlines from Northview to Marshfield, and thence south and southwest to Barry and in McDonald counties, were traced by Mr. Marbut during the summer of 1893. Northwest of Northview the limits were defined by Prof. Shepard. The result is necessarily generalized, and the outlines are only approximately correct. More detailed work with topographic maps is necessary for exact delineation. Within the marginal portion of the Lower Carboniferous area it is probable that patches of Silurian rocks are exposed, and, on the other hand, there are doubtless many outliers of Lower Carboniferous rocks within the Silurian area which are not shown. Along Finley creek, and north of Seymour, such exposures of magnesian limestone are known to exist, entirely surrounded by Lower Carboniferous beds. Similar patches are represented in McDonald county. The presence of such is due, probably, to irregularities of the surface of the Silurian rocks.

Stratigraphy and Sections.—The following sections and notes give a general idea of the nature of the rocks at different localities.

In township 31 N., 20 W., in S. W. ¼ section 15, Prof. Shepard reports the section of figure 19, along the Pomme de Terre.



Ft.
20. Sandstone, upper 15 ft. ferruginous, heavy bedded, soft and friable, grains rounded, cemented by magnesia and lime; lower layers coarser grained, irregularly bedded, often cherty.

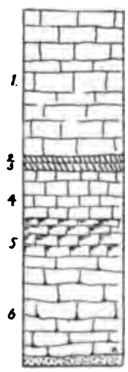
6. Magnesian limestone, coarse, light gray, distinctly bedded in thin layers, cherty in places.

5. Magnesian limestone, siliceous, compact, pinkish drab, much disturbed, fissured, shaly, cherty.

FIG. 19. Section on Pomme de Terre river.

The sandstone of this section is frequently exposed northwest of here, in township 31, N., 19, W., and in adjoining townships; also in fine bluffs along the Niangua river, where, Prof. Shepard reports, it is rarely over 20 ft. thick.

In township 27 N., 19 W., section 35, N. W. ¼, at the O'Haver mines, Prof. Shepard describes the section of figure 20.



Ft.

25 Magnesian limestone, fine-grained ("cotton rock").

2 Chert ("white flint").
2 Chert ("sand flint").

8 Magnesian limestone ("spotted cotton rock").

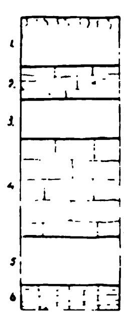
6 Magnesian limestone ("spotted cap").

15 Magnesian limestone, siliceous, dark red to yellow, hard and rather coarse grained, with small cavities.

Sandstone, saccharoidal.

FIG 20. Section at the O'Haver mines.

Near the mouth of Finley creek, he further describes the section of figure 21.



Ft.
10 Chert slope.

7 Highly siliceous, cherty limestone.

8 Chert slope.

20 Heavily bedded limestone; where weathered filled with small cavities.

10 Chert slope.

5 To bed of river, very thin-bedded, shaly limestone, "cotton rock."

FIG. 21. Section near mouth of Finley creek.

Near the mouth of Rock creek, on White river, is the bluff of Turkey mountain, which Mr. Marbut describes as exposing 400 ft. of magnesian limestone, beneath the base of the Lower Carboniferous. In this whole section no sandstone was seen, though a thin bed might have escaped notice. The rocks were shaly and massive, magnesian limestones.

On the state line, about a mile east of where White river crosses it, a section was examined by him under rather favorable circumstances. Here the section of the rocks is as is shown in figure 22.

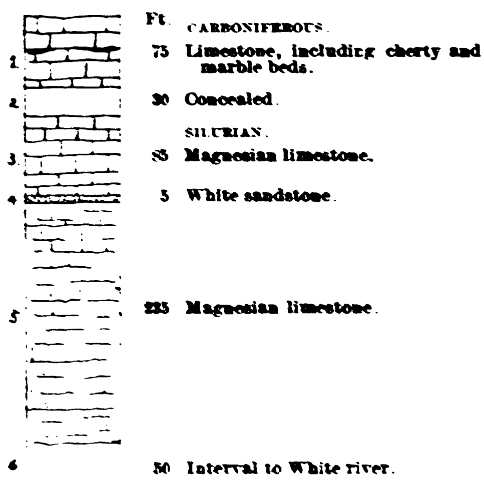


FIG. 22. Section near White river

In Springfield, these rocks have been encountered in drill-holes at a depth of about 300 ft. In the record of the hole at the Electric Motor plant, given in the next chapter, Nos. 13 to 16 belong to the Silurian, and aggregate about 150 feet in thickness.

Sandstones of the Series.—Sandstones, being readily distinguishable here, are serviceable for correlation; they were hence specially studied. They are recognized at several horizons, but are, apparently, not persistent. Mr. Marbut, in his recent examination of this area, measured and located all important outcrops of these sandstones which he encountered. His results are included in the following table. The altitudes were determined with the Aneroid barometer, and are at best only approximate. In the whole area examined, Mr. Marbut states that no sandstone more than 20 ft. in thickness, with possibly two exceptions, was seen, most of the exposures being only a few feet (5 to 10) thick.

LOCATION AND ALTITUDES OF SANDSTONE OUTCROPS.

No.	Township.	Section.	Altitude, A. T. Ft.	Thickness, Feet.	Notes.
1..	21N, 26W....	9..........	1000	....	....
2..	"	20..........	1060	....	Contact with Lower Carboniferous, 1 mile S.=1190′ A. T..............
3..	"	27..........	1170	5............	Altitude of river here=885′..................
4..	21N, 25W....	18..........	1000	15..........	Reddish=160′ above river
5..	"	20........	1035	....	....
6..	21N, 24W....	3..........	985	....	Contact 4 miles SE.=1100
7.	22N, 25W....	11..........	1095	....	Sandstone, fossiliferous, underlain by chert......
8..	"	12..........	1095	....	....
9..	22N, 24W....	18..........	950	....	....
10..	"	18..........	900	....	....
11..	"	9..........	980	....	Indurated................
12..	"	11..........	890	....	....
13..	"	11..........	855	....	Quarter mile south of last
14..	"	14..........	990	....	Sandstone blocks ½ mile south of last............
15..	22N, 23W....	16..........	850	Thin.......	On Wilderness road ......
16..	" ...	16..........	970	"	½ mile south of last.......
17..	22N, 22W....	17..........	1030	10..........	Whitish..................
18..	"	21..........	1070	....	About 280′ above river; only a few ft. below Carboniferous..............
19..	"	23..........	845	....	....
20..	22N, 21W....	17..........	1080	....	....
21..	"	17..........	1090	....	....
22..	"	17..........	1065	....	....
23..	"	16..........	955	....	Sandstone and chert .....
24..	"	10..........	925	....	....
25..	"	12..........	1100	....	....
26..	"	24..........	1115	....	....
27..	"	25..........	1210	....	Contact=1260′ (about)....
28..	23N, 26W....	11..........	1100	2............	....
29..	"	12..........	1095	....	....
30..	"	14..........	1100	....	About 150′ below contact.
31..	23N, 25W....	7..........	1090	....	....
32..	"	34..........	1030	....	....
33..	23N, 24W....	5..........	1020	....	Contact at 1130′..........
34..	"	8..........	950	....	....
35..	"	9..........	935	....	....
36..	23N, 21W....	3..........	900	....	Contact about 1150′......
37..	"	2..........	985	....	½ mile N. of last.........
38..	26N, 18W....	34..........	1100	15 to 20 . ..	On Guffy creek ....
39..	"	34 (same hill)	1200	Thinner.. ..	On Guffy creek ....
40..	27N, 19W....	SW portion.	1060	15 (about)....	On east side of Swan creek
41..	"	15..........	1000	25 plus	In bed of Swan creek at Boston ....
42..	26N, 18W....	3..........	1320	25 plus	Same as last, at county line, 320 ft. below base of Carboniferous ....
43..	26N, 17W....	6..........	1300 to 1400	25 plus	Same sandstone as last and about 100 ft. below base of Carboniferous........
44..	27N, 17W....	14..........	1500	Not so thick	30 ft. below contact......
45..	"	1 (?).......	....	Thick	50 ft. below contact .....
46..	"	1 (?).......	....	Thinner....	100 ft below contact ....
47..	28N, 16W....	27 (?).......	....	40..........	In bed of Bryant's branch.

The section of Turkey mountain, referred to above, compared with those along White river, yields evidence of the nonpersistence of these sandstone beds. Between No. 4 of the above table and Viola, Mr. Marbut notes a few outcrops of thin sandstone beds. These and other exposures he describes as follows: "The rocks, for more than 150 ft. above the river, on the east side of Kings river, at Viola, were well exposed in the road, but there was no sandstone visible up to that height." Other inconspicuous exposures of sandstone occur along Indian creek, but they all apparently represent very thin beds.

South of Kirbyville, near No. 27 of the above table, along the Harrison road, Mr. Marbut describes a bed of considerable thickness, about 50 ft. below the contact of the Carboniferous rocks. Such was seen here by the writer also. Quite close to the contact in this vicinity, large masses of white sandstone were also seen, but they did not occur in a continuous bed. They probably occupy a contact depression in the magnesian limestone, and represent local thickenings of the normally thin contact sandstone. Thus, about a mile north of the state line, and one-half mile east of Turkey creek, the contact sandstone is exposed at a spring, and is there only a few inches thick.

Opposite No. 44 of the table, several exposures of sandstone were seen by the writer, about two miles southeast of Chadwick, on the road to Barber creek. These observations are included in the following table:

		Bar.	Altitude.
1...	Chadwick	1575	1375
2...	Contact Lower Carboniferous	1430	1230
3...	Sandstone, brown, not over 10 ft. thick	1340	1140
4...	Magnesian limestone	......	....
5...	Slab of white sandstone	1280	1080

Between Garrison and Forsyth, the rocks exposed are almost exclusively magnesian limestone and cherts; no sandstone in place was observed, but fragments and slabs of sandstone were frequently seen, indicative of thin beds at various intervals, rather than of one or two formations of considerable thickness.

The sandstone No. 41, Mr. Marbut describes as follows: "This bed appears to be one of the most persistent within the area examined.

Up the creek from Boston, it rises, and on the county line (No. 42) it is at an elevation of above 1320 ft. A. T., while at Boston it is about 1000 ft. A. T. Just east of the Carboniferous escarpment, in section 6, township 26 N., 17 W., is an exposure (No. 43) of what is probably the same sandstone, at an elevation of between 1300 and 1400 ft. A. T., and only about 100 ft. below the base of the Carboniferous rocks, while at Boston it is as much as 250 ft."

"A bed of sandstone, apparently not so thick (No. 44) as the last, is about 30 ft. below the contact, some seven miles northeast of this, in section 14, township 27 N., 17 W., at an elevation of about 1500 ft. A. T., and again about two miles northeast of this on the Ava-Seymour road. Here are two exposures (Nos. 45 and 46), one 50 ft. below the contact, the other about 100 ft. below this. The top one was a rather thick bed."

"In the bed of Bryant's creek, about two miles southeast of Cedar gap, the heaviest bed of sandstone (No. 47), seen in the Magnesian series was exposed, having a thickness of 40 ft. to the creek bed."

"Dr. Shumard notes the occurrence of the Second sandstone about ten miles east of this. If this bed rises to the eastward, as those east of here appear to do, it would come to the surface of the upland at about this place. North of this, toward Cedar gap, a close watch was kept for any sandstone beds, and I feel pretty sure that none of any considerable thickness occur. In the hill south of Cedar gap, a thin bed, 2 to 5 ft. in thickness, is exposed about 60 ft. below the base of the Carboniferous rocks."

"North of this, the surface east of the Carboniferous escarpment, as far eastward as my observations extended, was so much obscured by the soil left from the decomposition of the vermicular sandstones, that no good exposures were seen. The country is not so rugged, and fewer opportunities for examining a thick section are given."

A study of the above table and notes shows that there are at least two beds of sandstone, and possibly more, in sections at several different points; but they are not persistent. This leaves out of consideration the uppermost sandstone, which occurs along the contact, and which is probably not a member of the series; this, as represented by No. 17 of the table, is, lithologically, very similar to the old Saccharoidal sandstone, and it is possibly at the same horizon. If this be the case, the so-called First Magnesian limestone, and overlying Trenton and other beds, are absent in many sections. Normally, this sandstone

is very thin—only a few inches; it has been recognized, by Mr. Oscar H. Hershey (apparently a careful observer), in northwestern Barry county; he describes it as usually very hard, fine-grained, slightly ferruginous, generally only 4 inches thick. In places it is a very hard, white quartzite, lithologically more nearly related to the magnesian rocks.

The Contact with Overlying Formations.— To cursory examination, the strata of the magnesian series are here apparently parallel with and conform to those of overlying formations. The question being one of considerable importance, special attention was given it during the past season's work, and we can not do better than to quote at length Mr. Marbut's conclusions:

"When we remember that the interval in time, represented between the deposition of the magnesian limestones and the Carboniferous rocks, was undoubtedly a long one, we should naturally expect to find a great unconformity. But, with the almost horizontal position of the rocks of the two series, such unconformity could not be everywhere apparent. Further, while the upper surface of the magnesian limestones is not absolutely level, the contact, viewed over a considerable territory, is seen to agree remarkably well in elevation at different places." Conclusive evidences of unconformity exist, however. Briefly enumerated, they are as follows:

1. "The occurrence of conglomerates, composed of water-worn chert pebbles, at the contact. These were not seen actually in place, but were observed in abundance on Jenkins creek, in township 24 N., 26 W., and over adjacent townships, always immediately below the contact."

2. "The existence at many places (and probably at most) of a coarse sandstone, just at the contact."

3. "The sudden lithologic and faunal changes, and the absence of Devonian and Upper Silurian beds, at least over most of the area."

4. "The irregularities of the contact line. The evenness of the contact line in a general way has already been referred to: that is, the line is at a pretty constant elevation, or the slope is gradual. The following table illustrates this. It gives the elevation of the contact at various places, commencing in McDonald county and going eastward down White river to the eastern limits of the Carboniferous rocks, and thence north to Marshfield. The elevations are based upon aneroid barometer readings, checked by reference to railway profiles, to level-

ing of the Geological Survey over the Aurora sheet, and to an estimated rate of fall of the larger streams:

ALTITUDES OF CONTACTS BETWEEN SILURIAN AND LOWER CARBONIFEROUS ROCKS.

Location.	*Altitude.*
Township 21N. 33W., Sec. 35, on Butler's creek	975 ft. A. T.
" 21N. 31W., " 17, Jane P. O., White Rock Prairie	1100
" 22N. 27W., " 27, Roaring river spring	1150
" 21N. 26W., " 29	1190
" 27N. 26W., " 27	1230
" 23N. 25W., " 32	1250
" 21N. 24W., " 4 (probably a fault.)	1280
" 21N. 24W., " 23	1100
" 22N. 23W., " 16	1090
" 22N. 22W., " 23	1150
" 22N. 21W., " 36	1225
" 24N. 18W., " 6	1205
" 24N. 16W., " 30	1280
" 26N. 19W., " 21	1200
" 26N. 17W., " 6	1480
" 27N. 17W., " 13	1350
Cedar Gap	1575
Marshfield	1500
Galena, Mo (by levels)	975

"The contact is seen from these figures to rise gradually, with small minor undulations, from west to east, the highest point being at Cedar gap, which is also the highest point within the area."

"On careful examination, however, it appears that at different places different rocks occur at the top of the system; thus, a few miles south of Marshfield, a sandstone lies at the top, while a few miles southwest of this, at Patterson's mill, on James river, there is no such sandstone at the contact. At a number of points, small patches of magnesian limestones extend peak-like up through overlying beds. Such 'buried hills' are on Jenkins creek, in Barry county, and in McDonald county. The lower beds of the overlying rocks apparently flank the sides of these prominences, and doubtless originally extended over them. These irregularities in the contact cannot very well be explained by a warping at the time of submergence, since they are too small and too abrupt."

"If the rocks of this system were above sea-level during the whole time intervening up to the Carboniferous, they must have been

deeply eroded. How is it, then, that evidence of a pronounced topography is absent? This may be explained in several ways: a) We can imagine the rocks having been submerged so deep during all of this time that no sedimentation could take place. This is difficult, if not impossible, to reconcile with the evidence of the proximity of shore lines and the formation of later Silurian and Devonian beds in surrounding areas. b) Again, we might assume them to have stood only a few feet under water—to have formed a submarine plain on which no deposition could take place. This would require an absolutely level or uniform contact line, which does not exist, and would also require a period of absolute quiet, so long that it is scarcely conceivable. c) Or, lastly, there may have been an erosion period, during which the magnesian limestones were above water long enough for them to have been worn down to a surface of faint relief. The amount of wear may have been great or small, dependent upon the height above sea-level. This is the most favorable explanation, I think."

5. "The fact that certain thick beds of sandstone in the system dip westward more rapidly than the contact line, as already described."

THE SILURIAN OF THE SOUTHEASTERN DISTRICT.

The Silurian rocks occupy almost the entire area of the Southeastern district, and contain all the important lead ore deposits. They consist mostly of massive beds of magnesian limestone, the strata being hundreds of feet thick in St. Francois county. The subdivisions recognized are shown in the table on page 331. They are almost entirely assigned to the Lower Silurian series.

A thin strip of Upper Silurian, too narrow to represent, was recognized by Shumard in Ste. Genevieve county. As already stated, some of the basal beds possibly belong to the Cambrian, but, for reasons given later, they are here included in the Lower Silurian.

Stratigraphic Limits.—The basal limits are the Archean granites or porphyries (perhaps the Cambrian in places). The upper limits are marked principally by the Lower Carboniferous, the Devonian and Upper Silurian being almost entirely absent. The latter fact shows that an erosion period must have intervened.

The distribution of these rocks is so plainly shown on the map that nothing further need be said. In the southern portion, around

the Archean area, the outlines of the map are the result of recent work by the Survey. In the north and east the older defined lines are used.

Stratigraphy and Sections.—To completely decipher the stratigraphy of the Silurian rocks in southeastern Missouri, will require much field work. This was contemplated in connection with future work of the Survey, and for the purpose of preparing reports upon the Mine La Motte and Bonne Terre sheets, which have already been surveyed. The importance of the subject to the mining developments recommends the early completion of this work. So far, observations have been made only along certain lines. As these throw much light upon the subject, we shall present them here, and shall accompany them with such provisional conclusions as the facts seem to warrant.

Mine La Motte and Vicinity.—Details of the stratigraphy of the country about Mine La Motte are given in such fullness in the description of the Mine La Motte estate in chapter XV, that they need not be introduced here. A brief outline will suffice. Immediately overlying the Archean crystallines is a great body of sandstone. This sandstone we have named the La Motte sandstone, and we consider it the basal member of the series. It has been penetrated by the drill to a depth of over 250 ft., without reaching bottom. It extends up the sides of the Archean hills, and thus tapers out. Overlying this is a series of limestone beds in which the ore is found. Near the base of these are the shales, containing the oft referred to Lingulella shells. This limestone is estimated to be as much as 200 ft. thick here. Above this massive limestone, which we correlate with the St. Joe limestone of St. Francois county, there are recognized in the hills a series of cherty magnesian limestone beds, which are assigned a thickness of nearly 300 ft.

From Mine La Motte station northward along the railway, the basal sandstone is continuously exposed, and again about Knoblick. Beyond this to the north, as we leave the Archean area, the higher lying limestone occupies the surface.

Doe Run and Vicinity.—The rocks of Doe Run and vicinity are also fully described in the mine descriptions given later. The basal Mine La Motte sandstone is recognizable here underlying the ore-bearing limestone, and also rising above the surface in high buttes along the granite outcrops, a few miles southeast of Doe Run.

Doe Run to St. Marys.—In the vicinity of Doe Run a large number of drill-holes have been put down, reaching the sandstone at increasing depths as one proceeds away from the Archean area. Along the St. Francis river, in the vicinity of Delassus, the overlying limestones are exposed. Continuing northeastward, however, the sandstone rises, and on the northern edge of Farmington it is only 107 ft. beneath the surface, though this point is at least 100 ft. above the river at Delassus. Still further east, on Wolf creek, the sandstone reaches the surface. Here, at Valley Forge mill, it is well exposed on the east bank, from near the level of the creek up the hill to a height of 100 feet and more. The rock is very ferruginous along joint-planes and over exposed surfaces, while the interior is often white and friable. Cross-bedding is exhibited at many points.

From this point eastward, along the Ste. Genevieve road, sandstone outcrops are frequent, reaching to the tops of the hills, which are probably as much as 200 ft. above Wolf creek.

Continuing thence eastward to where the west fork of Jonca creek crosses the road, near the N. E. corner of township 36 N. 6 E, sandstone was exposed most of the way down the hill slope, with some thin beds of grit or conglomerate of small quartz pebbles. About a mile beyond this, at the iron bridge over the next fork of the Jonca, is an outcrop of decomposed granite.

The La Motte sandstone appears, thus, to be nearly continuously exposed, and to be the only Silurian rock between Farmington and the Ste. Genevieve granite area.

At Shearlock's mill, on Jonca creek, south of Weingarten, high bluffs of sandstone are exposed on the north side, dipping about 10° SE. On the opposite side of the creek to the south, limestones are said to come in. This may be the result of the southerly dip, but the abruptness of the change suggests some faulting here.

East of Weingarten about two miles, on the Ste. Genevieve road, near the east line of section 19, outcrops of limestone were encountered near the hill top. Thence, down the hill, following a small tributary of Aux Vases creek eastward, limestone is almost continuously exposed, dipping about 5° E. At one point sandstone was observed to break the continuity somewhat, as is shown in the adjoining sketch. These limestones are abundantly exposed, in the hills, about the Cornwall copper mine, in section 22, and thence

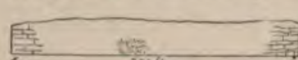


FIG. 23. Illustrating unconformity between sandstone and limestone.

down the creek to the Aux Vases church, near Janis's mill, in section 26, of the same township. The church is located upon a hill composed entirely of magnesian limestone; a mile and a quarter east of this are bluffs of the Crystal City sandstone, which dips from 5 to 10° E. of S. This sandstone is abundantly exposed, beyond here for a quarter of a mile, and is of the usual white, friable character. It is, in turn, seen to be overlain by limestones, somewhat thinly bedded, of white color, and compact texture.

Thence to St. Marys, a series of limestones are passed over which were not differentiated during the hasty trip.

Ste. Genevieve to Bonne Terre.—For a distance of about eight miles west of Ste. Genevieve, the Lower Carboniferous and Trenton limestone strata were passed over, dipping from 5° to 10° eastward; beyond these, the Crystal City sandstone was reached. The contact between this sandstone and the overlying limestone is well exposed, and was seen to be sharp, with no evidence of unconformity.

Thence, westward to Bloomsdale, beyond Establishment creek, this sandstone is frequently exposed in the hills. After this, the underlying magnesian limestone sets in and is continuously exposed, with a dip of from 5° to 10° eastward, as far as Punjaub mill, and a mile or so beyond it. The upper beds of this "St. Francois limestone" seemed to be more massive and rugged, while the lower beds were very flaggy and thinly bedded, and are in part very sandy.

The sandstone was distinctly seen underlying the limestone west of the mill, and southwestward, outcrops of it were encountered as far as where Terre Bleu creek crosses the county line. At this point, the sandstone plainly dips down again under the limestone to the west. The lower layers of the latter are here seen to be flaggy, thinly bedded and sandy, like those exposed on the eastern side. From here on to Bonne Terre, the St. Francois limestone is exclusively the surface rock.

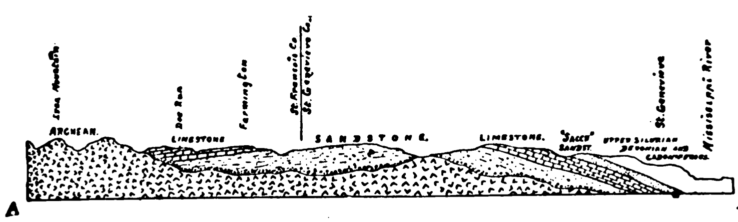


Fig. 24. Cross section from Iron Mountain to Ste. Genevieve.

These observations, though somewhat hastily made, seem yet sufficient to establish the fact that there is only one great body of

limestone here, which we have termed the St. Francois limestone, lying between the basal or La Motte sandstone and the upper, Crystal City sandstone. Further, the facts seem to show that there is an anticlinal axis running N. E. and S. W., about six miles west of Farmington. These conclusions are embodied in the following generalized cross-section.

Doe Run to Riverside.—Proceeding northward from Doe Run, along the Bonne Terre railway, the magnesian limestones of the St. Francois group are continuously exposed. That the La Motte sandstone exists below, is shown by the record of the shaft and drill-hole at the foot of Simms mountain, given in chapter XV. Drill-holes put down during the past year within a few miles north of the St. Francois river show the thickness of the limestone to reach as much as 600 ft., and the sandstone is found uniformly beneath it. This brings us to the Flat river mining district.

From this district northward, through Bonne Terre to Big river, is a strip of country which we shall consider in some detail in connection with the descriptions of the mines. Summarizing, a body of limestone 600 or 700 ft. thick is shown to be present here, under which sandstone, of undetermined thickness, is invariably encountered. The limestone is made up of beds which are often of great thickness, and in which the ore deposits occur. With these thick beds of limestones are some shales, but they are not persistent. As the sandstone is approached, the limestone becomes sandy. The upper beds, as exposed in the hills, are somewhat thinly bedded. From the mine descriptions it will be seen that the massive magnesian limestones constitute the bulk of the country rock.

Just south of the railway bridge over Big river, certain shale beds are recognized dipping slightly to the west. These are specially referred to in considering the stratigraphy about Bonne Terre, and are correlated with certain beds high in the hills south of that town. About a half mile north of Big river bridge, these same shales are exposed at intervals, for nearly three-quarters of a mile; in places they are as much as 10 ft. thick, and include thin layers of limestone. They are capped with thinner beds of limestone. Their continuance here indicates practical horizontality, but, as the railway grade rises, they disappear by degrees. East of the track, in the county road, these shales are also exposed, and a little north of this, drusy quartz is abundant over the surface, and characterizes the country northward to and beyond the Valle mines.

North of the 28-mile post, thinly bedded, shaly limestones continue exposed, though the shales are yellow and not green like those near the railway bridge. Beyond the 27-mile post, a dense, white limestone, 10 ft. thick, is exposed in a cut. Thence to the Valle mines no exposures of importance were observed along the railway, but over the county road, limestones crop out at frequent intervals.

At the tunnel, at the 24-mile post, which is about 300 ft. above the bridge over Big river, is a massive exposure of magnesian limestone, fully 50 ft. thick. It is of white color, siliceous in appearance, and containing many minute drusy cavities. This we consider one of the lower strata of the Potosi limestone.

Thence northward to the 22-mile post, a descent of 150 ft., are few exposures. About two-thirds of a mile farther north and 50 ft. lower, sandstone crops out in a bed about 5 ft. thick. It is of a red color, coarse texture, and is associated with limestone and chert. It dips slightly northward.

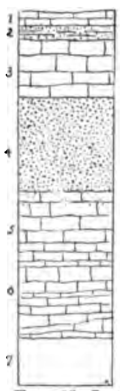
East of this, in the bed of Joachim creek, the rocks are very much disturbed; beds of sandstone and quartzite conglomerate are seen, dipping 30° N. and at other angles. This is plainly the point of crossing of a fault line, which will be referred to later.

Ascending the grade, between the 21 and 20-mile posts, thin layers of sandstone and chert are exposed in several cuts, overlain by limestone. About one-third of a mile beyond the 20-mile post, 20 ft. of limestone overlying about 2 ft. of shale is exposed, beneath which thin sandstone appears. About a third of a mile north of this, there is a slight reversal of the dip, and the thin layers of limestone, shale and sandstone rise to the north.

Between the 19 and 18-mile posts are cuts exposing about 20 ft. of limestone, shaly in part, underlain by red, coarse-grained sandstone, dipping quite sharply to the south. This sandstone does not, however, seem to be persistent, and runs out into shale and limestone. A mile or so farther north, similar sandstones and limestones are exposed with a northward dip. After this, limestone with shaly beds are exposed in the cut, though blocks of sandstone are found over the surface, until a point about a quarter of the distance between the 15 and 14 mile posts is reached. Here 3 ft. of white sandstone is cut through, but soon dips northward under the overlying limestone.

Thence northward, no significand expoures were seen for several miles. Midway between the 10 and 9 mile posts, on the west side

of the railway, about 2 feet of white, coarsely grained sandstone crops out, a little beneath the railway track. West of this, near the base of the hills, sandstone in thin layers, somewhat ferruginous, and mostly associated with limestone beds, crops out in a number of places. At higher levels, similar thin layers were also seen, and on the hill-tops nearly 150 ft. above the railway, blocks of sandstone are found.



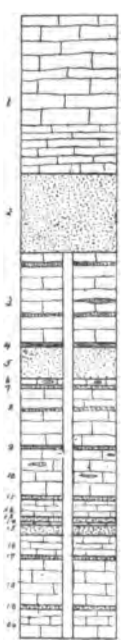
Ft.	JOACHIM LIMESTONE.
	High hill with occasional exposures of magnesian limestone.
3	Magnesian limestone, rugged.
	CRYSTAL CITY SANDSTONE.
3	Sandstone, thinly bedded, somewhat shaly.
12	Magnesian limestone, dense, hard.
20	Sandstone, massive, friable, indurated in places.
10	Magnesian limestone, dense; sandy layers near the top, and pebbles like quartzite.
20	Magnesian limestone, irregularly and thinly bedded.
10	Slope to the bed of Plattin creek.

FIG. 25. Section on Plattin creek.

On the east bank of Plattin creek, a little below the bridge opposite the nine-mile post, the section illustrated in figure 25 was measured by the writer.

About a mile and a half below this, sandstone was again seen in the bed of the creek at the site of the falls.

At the Crystal City Glass works, a little above the mouth of the creek, the section is given in figure 26.



Ft.	JOACHIM LIMESTONE
100	Limestone, dark, earthy, magnesian, shaly, brecciated, upper layers hard and dense, no chert.
	CRYSTAL CITY SANDSTONE.
50	Sandstone. white, friable, mined for glass works, exposed to bed of creek.
	ST FRANCOIS LIMESTONE IN DRILL-HOLE.
61	Limestone, blue and gray, with chert.
3	Shale.
14	Sandstone, white, with chert.
4	Limestone, " " "
1	Sandstone, " " "
37	Limestone, blue and white, with chert.
2	Sandstone, white.
30	Limestone, gray and white, with chert.
2	Sandstone, white.
12	Limestone, white, with chert.
10	Sandstone, with stratum of limestone.
13	Limestone, gray and white, with chert.
2	Sandstone, white.
29	Limestone, white and gray.
2	Sandstone, white.
18	Limestone, gray, with chert

FIG. 26. Section at Crystal City.

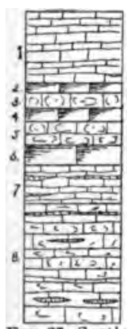
The sandstone rises northward, and is exposed on the railway, just beyond the 27-mile post, over 100 ft. above the creek. A cut occurs here, about 500 ft. long, through this rock. It is in massive beds, and also in shaly layers, often distinctly false-bedded. Thence it dips northward, and about half a mile farther north, along the railway, the top is

BLUFFS OF CRYSTAL CITY SANDSTONE AT CRYSTAL CITY.
From photograph by G. E. Ladd.

exposed in a series of small cuts 40 or 50 ft. lower. It is here capped with a sandy and brecciated limestone.

Over half a mile beyond this, in a deep rock cut crossed by a wagon bridge, about 20 ft. of thin, argillaceous, shaly, magnesian limestone (JOACHIM) is exposed, containing some free calcite, but no chert. The beds dip slightly northward. A mile or so east, at the mouth of Plattin creek, the rocks in the bluff are seen to dip about 5° NE.

Between Herculaneum and Riverside is an almost continuos exposure of Trenton limestone in high bluffs. These beds must overlie those of the last described exposures. A section measured about midway between the two points, is shown in figure 27.



Ft.		
	TRENTON LIMESTONE.	
15	Limestone, thinly bedded.	
2	"	massive.
3	"	pitted, rough surface.
3	"	massive
5	"	pitted, like No. 3.
4	"	massive, dense, very persistent.
8	"	shaly and thinly bedded, with layers of chert.
25	"	shaly, drab, pitted and rough surface; portions of dense texture, like lithographic limestone, contains patches and seams of an earthy limestone, which weathers yellow and soft, and, on removal, leaves the rock with a honey-combed appearance; fossiliferous, pellucid chert in isolated, small, lenticular, thin layers parallel to the stratification; to railway level about 30 ft. above river.

FIG. 27. Section betw. Riverside and Herculaneum.

No. 8 of this section is traversed by vertical crevices, but no faulting was observed; these crevices are enlarged in places to the size of small caverns; horizontal openings are also observed.

These notes are confessedly unsatisfactory for determining the relations of the Crystal City sandstone to the St. Francois limestones farther south. The extension of this sandstone at a low level up Plattin creek is difficult to reconcile with the section across Ste. Genevieve county. Either it is at this low level by reason of a fault, or it splits into thin, insignificant layers, and is thus represented southward almost to the Valle mines, where it may rise above the magnesian limestones. This interpretation is expressed in the following generalized cross-section:

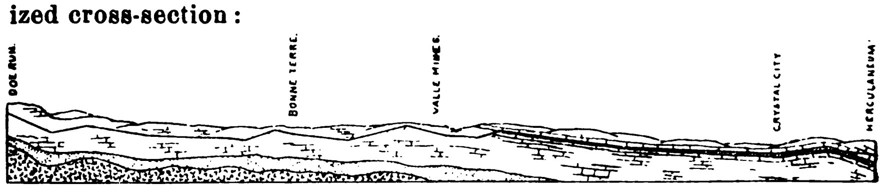


FIG. 28. Cross-section from Doe Run to Herculaneum.

Bismarck to Silica.—South of Bismarck and west of Iron Mountain, the Silurian rocks have been fully described in the recently issued Iron Mountain sheet report. Sections are given showing the presence of the basal Iron Mountain conglomerates and overlying La Motte sandstones; above these are the St. Francois limestones, several hundred feet thick. About Belleview are sandstone beds in the upper portion of the limestone column.

In the vicinity of Bismarck, the St. Francois limestone is the country rock. Between that place and Irondale, these magnesian limestones appear to be horizontal, and continue so north of Irondale.

At the bridge over Big river, two miles north of Irondale, are massive and shaly beds of magnesian limestone; at the north end they dip 5 to 10° northward, but they soon resume their horizontal position.

North of Hopewell, the limestone contains much drusy quartz, and, near Summit station, about 200 ft. above the bridge over Big river, is a long cut exposing pinnacles of magnesion limestone surrounded by red clay containing much of this quartz.

At Mineral point, horizontal beds of magnesian limestone are exposed, and are seen continuously for a mile northward. Between this point and Cadet are a number of cuts exposing similar pinnacles of limestone and drusy quartz.

At Cadet, and thence down Mill creek to Lawson and beyond, exposures of magnesian limestone are frequent, and the beds appear to be practically horizontal.

At Blackwell are bluffs of horizontal magnesian limestone beds, containing drusy quartz along the joints, and similar rock is exposed north of that place.

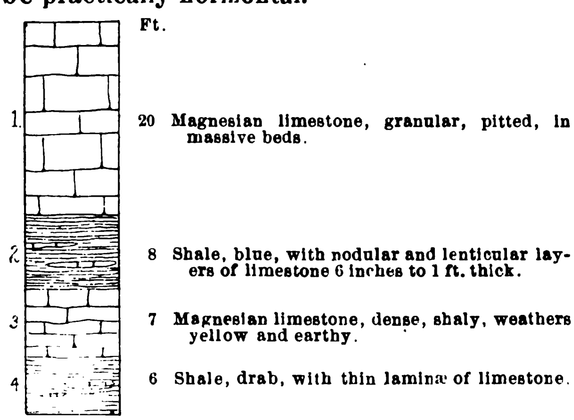


FIG. 29. Section on Big river.

In the railway cut on the north side of Big river, figure 29 was measured.

From the south end of this cut northward, a

distance of a mile, these beds are continuously exposed, lying in a practically horizontal position. Beyond this, they dip northward, and overlying, granular, pitted, thickly bedded magnesian limestone comes in, dipping from 10 to 20° NE., for a distance of about 1000 ft. From here to nearly a mile beyond Vineland, the rocks are very much disturbed, being violently flexed and faulted. The adjoining figure 30 illustrates the disturbances here. Though the rocks just south of Vineland are dipping as much as 40° northward, within a half mile west of that point they assume an almost flat position, or are dipping a little southeast. These disturbances mark the crossing of a fault, which we have referred to, north of the Valle mines. It has also been observed west of here, toward Frumet, and is undoubtedly of structural importance.

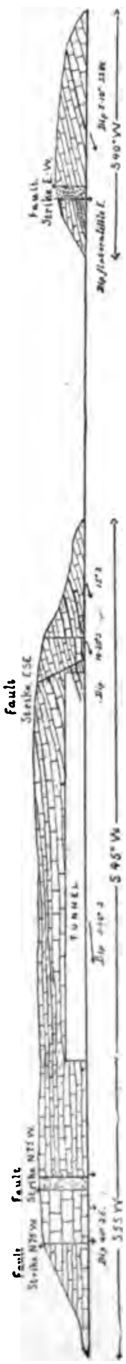


FIG. 30 Cross-section along railway, illustrating disturbances near Vineland.

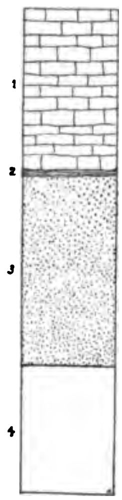
Beyond Vineland, to DeSoto, the rocks are thinner bedded, more shaly, and of white or buffish colors; they also appear to be horizontal, and are plainly so at De Soto. From DeSoto to Silica, beds of the same character and similar attitude are frequently exposed in the hill-sides, and not until we reach Silica does the Crystal City sandstone appear. It there occupies a position high up in the hills, apparently overlying the rocks to the south.

Potosi to Palmer.—About Potosi, limestone containing chert and drusy quartz, such as is exposed at Summit and Mineral point, constitutes the country rock. West of Potosi, to Palmer, similar limestones and cherts are exposed, together with some sandstone. On nearly all of the hill-tops and slopes, blocks and fragments of sandstone are found; also a few outcrops. Detailed stratigraphic work is necessary to define the distribution.

Northwest of Palmer, down Fourche a Courtois about 9 miles, and on the west side, sandstone outcrops are also found, not far above the creek bottom. On the hill-tops beyond this are sandstone blocks, and an exceedingly sandy soil shows the presence of a considerable body of this rock. North of Palmer five or six miles,

sandstone outcrops were also seen. No doubt there are several thin beds interstratified with the limestone here.

Pacific to Labadie and Tavern Rock.—In the hill just above the railway, in the town of Pacific, the section, figure 31, was measured.



Ft.

50 Limestone, very thinly bedded, in layers 2 ft. and less; drab color, weathers buff; dense and somewhat crystalline; magnesian and siliceous, containing some free calcite; a few layers of cotton rock.

1 Shaly layer, greenish color, with nodular concretions.

60 Sandstone, friable, mined for the manufacture of glass (Crystal City sandstone).

40 Slope to railway level.

FIG. 31. Section at Pacific.

Westward, up the railway, at the 39-mile post, is an exposure of massive brown sandstone, while half a mile beyond, higher up the grade, thinly bedded magnesian limestone is exposed, which belongs beneath the sandstone. About half a mile east of Gray's Summit is a cut 600 ft. long, exposing at the north end thinly bedded cotton rock, about 10 ft. thick, overlain by sandstone, as illustrated in A of figure 32. The sandstone is massive, with bedding partially developed, the exterior brown, while the interior is comparatively white, soft and friable. At the contact is a pale green, argillaceous shale, 2 to 3 ft. thick, containing nodules and broken layers of chert. This shale is much crushed, and the lower surface of the sandstone above is studded with angular fragments of quartzite and chert. The sandstone is plainly unconformable upon the limestone. Under the wagon bridge, just beyond Gray's Summit station, is a section, illustrated by B, in figure 32. The magnesian limestone is here mostly in thin and shaly layers, and is very much fractured; some thick beds occur, but they are not persistent. No chert was noticed. The same

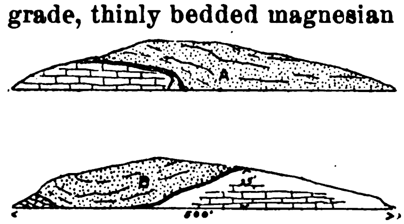


Fig. 32. Unconformity of sandstone and limestone near Pacific.

green shale with chert fragments occurs at the contact. The unconformity of the sandstone upon the limestone is very plain.

Thence, down the grade toward Labadie, the underlying magnesian limestones are exposed in a number of cuts. They are mostly thinly bedded and in horizontal layers; some thicker beds, with a nodular structure, also occur, and a few sandy beds were seen in which the sand occurs in small lenticular patches in the limestone. Near the bottom of the series, thinly-bedded cotton rock comes in.

Proceeding from Labadie, along the St. L., K. C. & C. railway, a distance of a mile and a third, an outcrop of sandstone in the river bluff, illustrated below in figure 33, is exposed. This great sandstone mass evidently occupies what was a depression or cavity in the underlying magnesian limestone, and is perfect evidence of unconformity. About half a mile farther east, sandstone is again exposed in a cut.

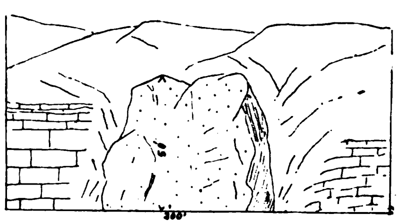


Fig. 33 Unconformity of sandstone and limestone near Labadie.

Thence, 600 ft. east, we come to a long bluff about 40 ft. high. This is composed of magnesian limestone in both shaly and massive layers, with some cotton rock; about half way up the bluff is a bed of hard sandstone or quartzite, about 3 ft. thick.

At Tavern Rock, the Crystal City sandstone is exposed fully 50 ft. thick, reaching to about 80 ft. above the river. This sandstone forms a bluff down the river for some distance, and is seen to be overlain by magnesian limestone, perfectly conformably.

Above Tavern Rock, about a half mile, the sandstone again appears and forms an almost continuous bluff for half a mile westward. The sandstone as first exposed here is about 50 ft. thick; it is massive, and bedding planes are scarcely visible. The bottom of the sandstone soon rises above the track, and undulates from the track level to a height of 20 ft. above it. The contact with the underlying limestones is thus very irregular, though no fragments of limestone are seen in the sandstone. The sandstone plunges down suddenly into the limestone, occasionally filling pockets 10 to 15 ft. deep. Blue shale about 2 ft. thick occurs constantly along the contact, like that described above. Above this, the base of the sandstone is filled with quartzose and cherty concretions and nodules. Beyond this to the west, the limestone above described comes in.

In Franklin County.—Southwest of Labadie, in Franklin county, sandstones are abundant, but their exact stratigraphic relations have not been studied. The Crystal City sandstone is represented at a number of points, under conditions that show it to be unconformable with the underlying rocks. Northeast of Dry Branch, on the Bourbeuse creek, sandstones are found over the hilltops which contain numerous fragments and small specks of chert. This shows that they were formed after the consolidation of the underlying chert beds.

FIG. 33*a*. Record of Sullivan drill-hole No. 1.

Near Sullivan, on the southern line of the county, a deep hole was sunk during the past year, which reached decomposed granite at a depth of 1200 ft. This gives a measure of the thickness of the Silurian rocks here.

The above record was kindly obtained for the Survey by Dr. W. A. Metcalf, from the drillers' notes.

THE SILURIAN OF THE CENTRAL DISTRICT.

In the Central, even more than in the Southeastern district, the Silurian are the prevalent rocks; they also contain all of the lead and zinc deposits. Only in the extreme western and northwestern parts are small areas of Lower Carboniferous.

The aggregate thickness of sections exposed is not far short of 600 ft. Beneath this the depth is unknown. At Jefferson City, a drill-hole put down 1200 ft. did not reach the bottom. Here, as in the southwest, all the rocks are of Lower Silurian age and belong to the Ozark stage. A provisional division of this stage is given in the table on page 331. A study of this table and of the following sections shows that two sandstone horizons are recognized. One of these, the lower, seems persistent over a long distance, but does not appear to continue eastward as far as Jefferson City. The other, and upper, is not constant, and changes partly to limestone within the limits of exposure. Several other minor beds of sandstone were observed in some sections.

A certain grouping of chert beds, or of alternate chert and limestone beds, suggests the possibility of separation on lithologic grounds from the thick, massive limestone beds exposed in the same series. This may prove convenient in the future, but we do not think that there is any paleontologic reason for it.

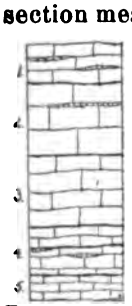
Limits exposed.—The upper limits of the Silurian rocks are marked by the Lower Carboniferous rocks exclusively. At different points, however, either Kinderhook or Augusta beds may be at the contact, as is illustrated by the later described Osage river sections. In places, deposits of Coal Measure shales fill pockets in these rocks. These facts are all evidences of unconformity, proving that one or more erosion periods intervened between the formation of the rocks.

Distribution.—The distribution of these rocks over the district is so clearly shown on the map that nothing further need be said. The western limits, or the outlines of the Carboniferous are almost entirely the result of recent work.

Stratigraphy and Sections.—Over this area considerable detailed stratigraphic work has been done. This has been principally along the Osage and Missouri rivers. The results, being of importance to the stratigraphy of the whole Ozark uplift, we shall record in considerable detail.

Osage River Sections.—Observations along the Osage river were begun at Osceola, a little west of the district line, and continued thence to the mouth of the river. For the sake of completeness, we shall include the whole series here. On the small map opposite this page are shown the outcrops of the different sandstones and the locations of the principal sections described.

In the hills and railway cuts about Osceola, we have exposed great thicknesses of the coarsely granular Burlington limestone, overlain, possibly, by the Keokuk, and underlain by the Kinderhook stage. A section measured in the town is shown in figure 31.



Ft. LOWER CARBONIFEROUS.

8. Limestone, gray, crystalline, with nodules and lenticular layers of chert.

15. Limestone, gray, massive, abundance of crinoids, lenticular chert layers along stratification planes.

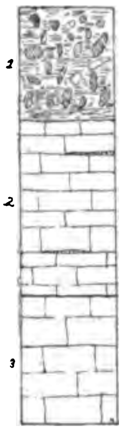
15. Limestone. buffish, earthy, comparatively few crinoids.

10. Limestone, thinly bedded, drab and buff, with irregular nodules and layers of chert

5. Limestone, dark drab color, very dense, thinly bedded, with nodules of black chert (Louisiana limestone) to river level.

FIG 31. Section at Osceola.

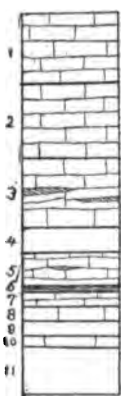
Just below the lower railway bridge, the following cection was measured:



	Ft.	
		LOWER CARBONIFEROUS.
1	35	Slope, large blocks of crinoidal chert and small fragments of same; also small fragments of decomposed, ferruginous sandstone.
2	55	Limestone, coarse, white and drab, with a profusion of crinoid stems and chert nodules.
3	40	Limestone, buffish, upper 10 ft. somewhat crinoidal, lower 10 ft. earthy, yellow and massive.

FIG. 36. Section at Station 1.

Thence, down the river, limestone is exposed at frequent intervals in horozontal beds. Just below the mouth of the Eaubleu, the following section was measured:



	Ft.	
		LOWER CARBONIFREOUS.
1	15	Limestone, thin layers, gray, with crinoid stems at intervals.
2	15	Limestone, thin layers, yellow, earthy, crystalline, with small crinoids.
3	15	Limestone, thin, gray, finely crystalline, crinoid stems; black, nodular chert of the Louisiana limestone.
		LOWER SILURIAN.
4	5	Slope.
5	7	Magnesian limestone, checked, irregular, buff, concretions of horny chert, mottled.
6	½	Shale, very soft, green, enclosing layers of limestone.
7	8	Limestone, thin, shaly layers, drab, earthy.
8	8	Limestone, massive layers.
9	3	Slope.
10	2	Limestone, hard, fine-grained, crystalline.
11	10	Limestone, earthy, yellow, soft, at intervals to river bank.

FIG. 36. Section at Station 4.

The magnesian limestone, shown at the base of the last section, is exposed down the river for nearly two miles; but, at the mouth of Bear creek, Lower Carboniferous rocks composed the entire bluff, from the water's edge upward.

About two miles further down, the following section was measured:

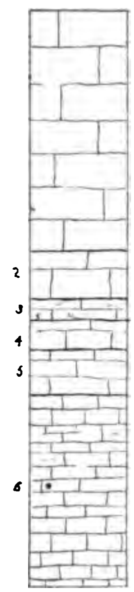


Fig. 37. Section at Station 10.

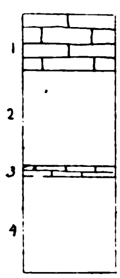


FIG. 38 Section at Station 16.

Beyond this, the Silurian magnesian limestones are exposed at frequent intervals along the lower bluffs of the river.

About ten miles farther down, Lower Carboniferous rocks again come in at the top of the bluff, and here the section of station 16 was measured.

Over the next two miles, the Lower Carboniferous rocks appear to come down to the water level, indicating an unconformity of contact, as no decided dips are observable.

At station 18, the contact is about 5 ft. above the high water level, and, from here on, the Lower Silurian rocks occupy continuously the lower part of the bluffs, the Lower Carboniferous rising higher and higher.

Just above Baker postoffice we have the section of figure 39.

Here the contact is about 90 ft. above the water level; at station 22 it is fully 130 ft.; at station 23 it is less than 100 ft., while at station 24 it is less than 60 ft., as is exhibited in section of figure 40.

Beyond this, the magnesian limestones are prevalent. At station 26 the bluffs rise directly from the water level to a height of 110 ft., and are composed entirely of magnesian limestone. This is mostly in massive beds, and is associated with some oolitic chert. At station 27 is a hill of similar rocks 180 ft. high. This bluff is continuous for two or three miles to station 28. At 29 are bluffs about 200 ft. high, exposing magnesian limestones with characteristic pitted weathering,

forming rounded, sugar-loaf-like hill-tops. These bluffs continue down the river for over a mile. Below this, above Hogle's creek, on the

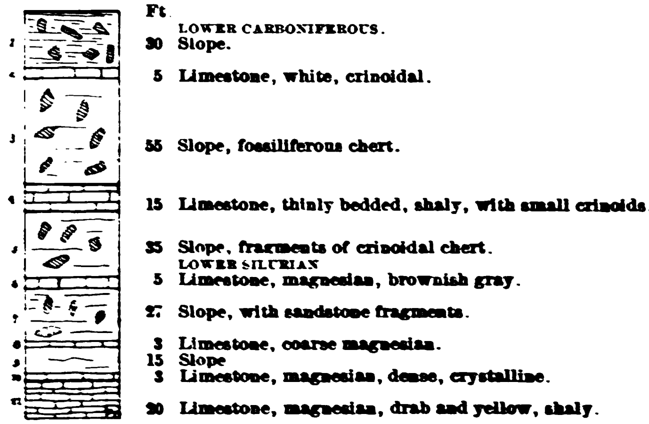


FIG. 39. Section at Station 20.

north side of the river, is a line of bluffs composed of massive beds of coarse magnesian limestone; chert fragments are abundant over the surface; the beds are practically horizontal. Thence, down the river three or four miles, the bluffs are continuous. The magnesian limestone is mostly in massive beds, with no sandstone; they are generally horizontal, but undulate slightly in places. About two miles below the Pomme de Terre, figure 41 was measured.

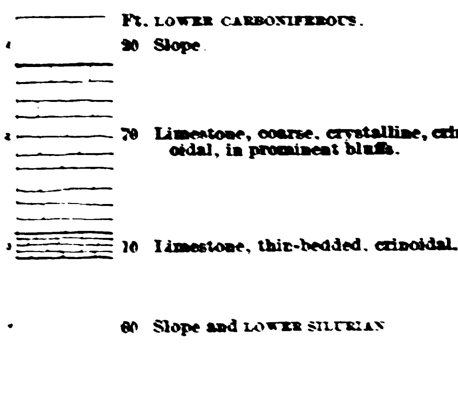
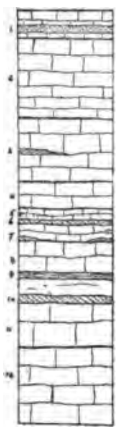


FIG. 40. Section at Station 24.

From this it appears that the contact between the Lower Carboniferous and Silurian rocks is about 120 ft. above the water level. No unconformity is observable in this one exposure. A mile farther down figure 42 appeared.

Below Holloway island, the river flows at the foot of high, palisade-like bluffs, composed principally of Burlington limestone. These continue intermittently down to Warsaw. Near station 36 there are no exposures in the lower 100 feet; but, at the western extremity of this bluff, magnesian limestone extends up to perhaps 50 ft. Below this the adjoining section of figure 43 was measured.

At Warsaw, the rocks in the town are the characteristic rough, thickly-bedded magnesian limestones. Along the bluffs beyond the island below the town, magnesian limestone is again exposed. It here undulates a little, and a few faults of two or three feet throw were observed; it is noteworthy that these were the only faults seen between here and Osceola.



Ft. LOWER CARBONIFEROUS
4 Limestone and chert in thin beds.

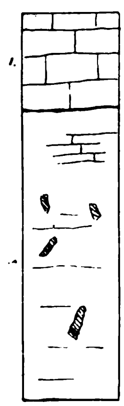
LOWER SILURIAN.
26 Magnesian limestone, cotton rock.

26 Magnesian limestone, irregularly bedded with nodular chert.

8 " " drab, crystalline, massive.
2 " " shaly.
1 Chert, nodular.
4 Magnesian limestone, massive, cherty.
11 Cotton rock.
1 Shale, drab.
4 Slope.
2 Chert and quartzite.
13 Magnesian limestone, coarse, rugged, cherty.

25 Magnesian limestone, massive, weathering in characteristic forms.

FIG. 41. Section at Station 33.

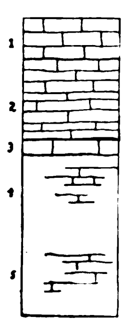


Ft. LOWER CARBONIFEROUS.
60 Limestone, coarse, crystalline, in massive beds.

Limestone, thinly bedded, crystalline, drab.

180 Slope, with blocks of chert.

FIG 42. Section at Station 34.



Ft. LOWER CARBONIFEROUS.
25 Limestone, heavy-bedded, gray, crystalline, crinoidal.

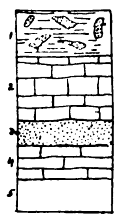
45 Limestone, thin-bedded, gray, crinoidal
LOWER SILURIAN.
10 Limestone, cotton rock.

100 Limestone, magnesian, thick-bedded, cherty at intervals.

Limestone, cotton rock at intervals.

FIG 43 Section at Station 36.

Thence down the river for about eight miles, magnesian limestones are continuously exposed.

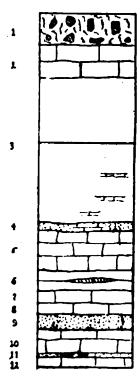


Ft.	
	Hill-top covered with fragments and blocks of ferruginous sandstone.
15	Slope.
20	Magnesian limestone, buff, with the usual pitted appearance.
8	Sandstone, buff, coarse-grained.
10	Magnesian limestone, buff-colored.
10	Slope to river level.

FIG. 44. Section at Station 42.

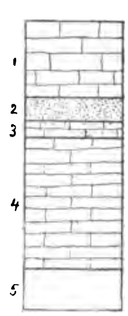
About two miles above Turkey creek, in the north bluff of the river, the first exposure of what we have named the Cole Camp sandstone was seen, as is represented in figure 44.

From this point down the river, the beds of the above section are continuously exposed at about the same level to station 43. Here the section of figure 45 was measured.



Ft.	
20	Slope, chert fragments.
20	Limestone, magnesian, gray, earthy, thick-bedded.
40	Slope, fragments of magnesian limestone and sandstone.
50	Slope, outcrop of magnesian limestone, nodular and pitted.
5	Sandstone and magnesian limestone.
25	Limestone, magnesian.
12	Limestone, magnesian, cherty.
8	Limestone, magnesian, massive.
7	Limestone, magnesian, nodular, coarse, yellowish.
3	Sandstone, heavy bedded, gray and white.
15	Limestone, magnesian, gray, nodular.
1	Sandstone and oolitic quartzite.
6	Limestone, magesian, drab, nodular.

FIG. 45. Section at Station 43.



Ft.	
	Top of hill covered with loose limestone and chert boulders.
40	Magnesian limestone, yellow, earthy.
12	Sandstone, nearly white.
8	Limestone, siliceous, nearly quartzite.
70	Magnesian limestone, siliceous, yellow.
20	Slope.

FIG. 46. Section at Station 44

From this station, nearly to Cole Camp creek, the sandstone stratum is plainly traceable, undulating from the water level to about 40 feet above it. Opposite the mouth of that creek it shows plainly and is there some 60 ft. above the river; it sinks to about 20 ft. within half a mile farther, after which no sandstone is seen for over a mile; then, in a bluff on the north side, figure 46 was obtained.

From this it appears that the sandstone is over 100 ft. above the river level at this point.

About four miles below, at the mouth of Deer creek, sandstone is found at about the same level, as is illustrated in figure 47.

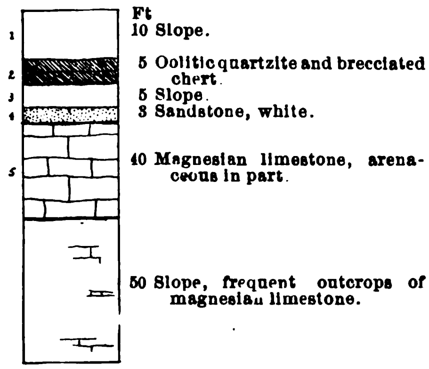


FIG 47. Section at Station 45

It is doubtful whether the sandstone at the top of these last two sections is the same as that of the preceding sections. It is different in character, and much thinner.

Three miles further down, on the Morgan county line, is a bluff 200 ft. high of almost continuous exposures of magnesian limestone, from 20 ft. to 190 ft. above the river. No trace of a sandstone bed was observed in the bluff, but opposite the mouth of Buffalo creek is an interesting example of what is known as a sandstone dike. A great mass of sandstone rises abruptly from the water's edge 50 ft. above the river. It is fully 100 ft. wide, and magnesian limestone in undisturbed beds runs up to it on both sides. It is undoubtedly the filling of a pre-existing crevice or cavity in the magnesian limestone. The lower part is of very open texture, being filled with small and large cavities, as if included fragments of limestone had been dissolved out. Chert fragments are also held in it. This mass indicates the presence of an overlying sandstone bed at no great height.

Between the mouths of Buffalo and Little Buffalo creeks is a bluff nearly 300 ft. high. Near the top of this bluff are several layers of sandstone or quartzite within a thickness of about 15 ft. Below this, for 270 ft. to the river bottom, are almost continuous exposures of magnesian limestone, yellow and earthy, and including some cotton rock. Some of these are rather siliceous, others are crystalline, but no sandstone beds were seen. From 100 ft. above the river bottom upwards, there are many blocks of sandstone, but no stratum could be found. The capping quartzite was in part a breccia of chert. The strata of these bluffs extend for over a mile, and are perfectly horizontal.

About a mile below the mouth of Little Buffalo creek, the section of figure 48 was measured.

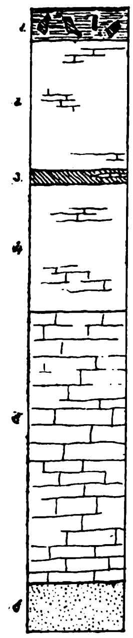


FIG. 48. Section at Station 49.

The sandstone at the base of this section is exactly like that exposed at the mouth of Cole Camp creek, and is entirely different from that of intervening exposures. It is entirely different from the quartzite capping the preceding high bluff. These facts, and its low position topographically, lead us to conclude that the Cole Camp sandstone is beneath the river level above station 49.

From this last point down the river, nearly to Crittenden, the sandstone is almost continuously exposed, rising from the water's edge to 20 ft. above it, in gentle undulations ; it maintains a thickness of about 20 ft. The contact with the underlying magnesian limestone is decidedly irregular. This may be due to the plunging flow of the water at the time of deposition of the sandstone, which is indicated by the cross-bedding of the latter.

Below Crittenden, the sandstone is again exposed in the river bank, and soon rises well above the water level. At station 53 it is about 20 ft. thick. The bluff is here about 215 ft. high. Exposures of magnesian limestone are continuous from the top of the sandstone to within 50 ft. of the top of the bluff. Much chert is associated with the limestone.

Beyond the mouth of Proctor creek, the base of the Cole Camp sandstone is fully 100 ft. above the river, and is as much as 25 ft. thick. Here we obtained the greatest exposure of the underlying Proctor limestone beds. These are magnesian limestone, in layers 5 to 10 ft. thick, very massive, but not specially distinguishable from the overlying Osage limestone beds, though perhaps less cherty.

At station 55, the sandstone reaches water level and disappears from view. Thence down the river it is exposed at intervals, as indicated on the map. The thickness remains about 20 ft.

At station 60, the section of figure 49 was measured.

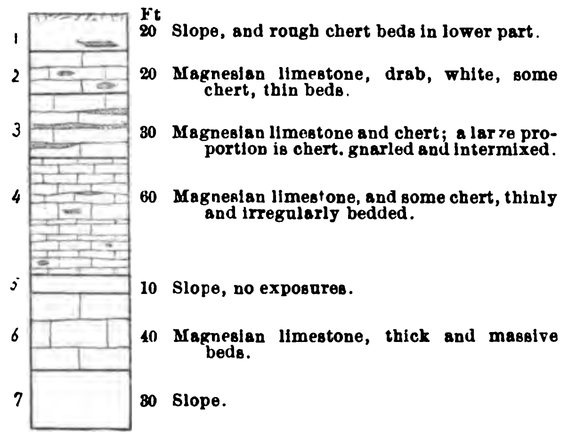


FIG. 49. Section at Station 60.

Below this, at station 61, the sandstone rises suddenly with a sharp but short dip of about 20°, to a height of about 50 ft. Following down to the loop of the river, at station 62, it is only 5 ft. above the water. Thence, around the loop, it rises again to a height of 40 ft. at station 61, to sink immediately after below the river level, thus clearly expressing an anticlinal flexure. From there down to the mouth of the Niangua river, the Osage evidently flows along a synclinal axis, the sandstone being continuously below water level.

Just above the mouth of Linn creek, at the boat landing, is a bluff composed entirely of magnesian limestone from base to top, the upper 40 ft. very cherty. The total height of the bluff is 110 ft.

At station 66, the sandstone again makes its appearance, rising out of the water with a sharp dip and some little faulting, as is exhibited in the adjoining sketch. It continues exposed for over a mile, after which it again sinks beneath the water.

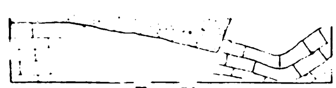


FIG. 50.

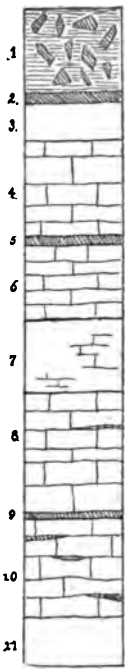
The flexure is evidently the continuation of the anticline above the Niangua.

At station 68, are prominent and very high bluffs, the summit being as much as 300 ft. above the river level. Of this bluff the section of figure 51 was measured.

The Cole Camp sandstone must be close beneath the water-level. The numbers 4 to 6 of this section form a prominent escarpment which overhangs the river for some distance down. At station 69, the base of

these beds is at a considerably lower level, being only about 50 ft. above water; at station 70, it is only 10 ft; thence, down the river for three or four miles these bold bluffs continue, the massive beds keeping above water level.

At station 72, 2 miles below Gravois mills, the sandstone again makes its appearance, and is exposed at intervals for over two miles, a little above the water level; the full thickness is here only 10 or 12 ft.



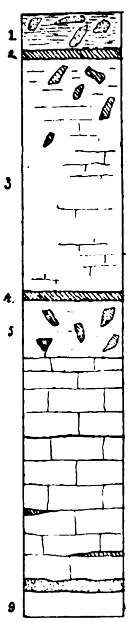
	Ft.	
1	35	Slope covered with fragments of oolitic chert. No sandstone seen.
2	5	Chert, very rough, like a breccia.
3	15	Slope.
4	40	Magnesian limestone, gray, very pitted weathering, massive and thick beds, no chert.
5	3	Chert, gnarled, with limestone.
6	30	Magnesian limestone, gray, very much pitted.
7	30	Slope, a few outcrops magnesian limestone.
8	50	Magnesian limestone, less chert and narrow drusy joints.
9	3	Beds of white chert.
10	40	Magnesian limestone, with chert in nodular masses and irregular layers.
11	20	Slope to river.

FIG 51. Section at Station 68.

At station 74, just above Bagnell, the sandstone rises above the river again for a short distance, as exhibited in figure 52.

Most of the interval of No. 3 of this section is seen in the river bluff to be occupied by massive beds of magnesian limestone.

At Bagnell, the sandstone is beneath the water, and is not exposed; but, about 5 ft. above the water, is a contact between an underlying very cherty magne-



	Ft.	
1		A few thin and small slabs of limestone found at the summit.
2	5	Massive bed, brecciated chert.
3	120	Slope. occasional outcrops of magnesian limestone in lower portion, upper portion covered with dense oolitic chert.
4	2	Chert bed.
5	30	Slope, chert fragments.
	40	Magnesian limestone, thick beds, pitted weathering.
	75	Magnesian limestone, cherty, especially in lower part.
	5	Sandstone, ferruginous.
9	10	Slope to river level.

FIG. 52. Section at Station 74.

sian limestone, and an overlying rock destitute of chert, but of very open texture, similar to that found at Tuscumbia, later described.

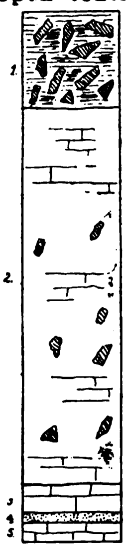


FIG. 53. Section at Station 76.

Thence, down the river for two or three miles, the left bank is bordered by bluffs 200 or more feet high, composed of massive magnesian limestone.

At station 76, sandstone appears again, but of much diminished thickness. Figure 53 is a section of this bluff.

Half a mile farther, this sandstone is 40 ft. above the river, and is 6 ft. thick. The contact with the underlying limestone is irregular and unconformable, like that of the sandstone traced higher up the river. Its thickness is variable, from 2 to 6 ft.; and, at times, it appears to pinch out entirely between the underlying and overlying limestones. This is the last appearance, down the river, of the Cole Camp sandstone. At Tuscumbia, an interesting bluff of magnesian limestone and chert is exposed, illustrated by figure 54.

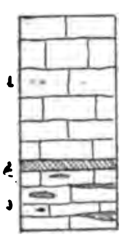


Fig. 54. Section at Tuscumbia.

South of the river, the hill rises to 200 ft. above the bottom, and is made up essentially of magnesian limestone, with an abundance of chert near the top; no sandstone was seen.

Down the river to Humphreys creek, magnesian limestone and chert constitute the bluffs. These rise above the river to heights of 200 ft. and more. The upper portions are composed of massive beds, aggregating at times as much as 100 ft. in thickness; little chert is associated with this. No sandstone was seen.

At Station 83 the following section was obtained:

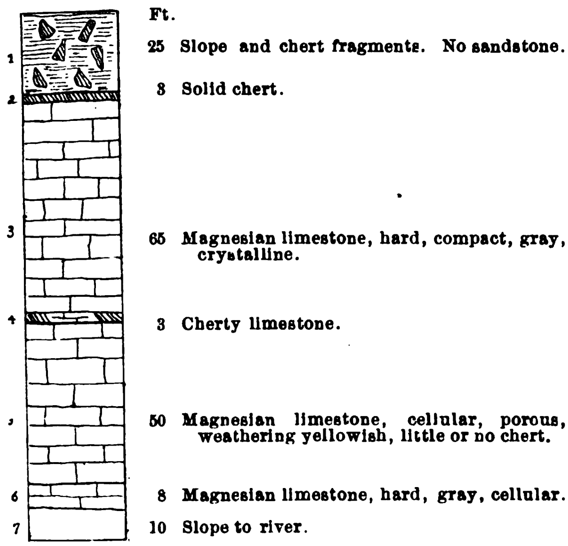


Fig. 55. Section at Station 83

The hills at the mouth of Tavern creek are made up of the usual series of massive limestone, with thinner chert beds. These form bold bluffs 100 feet or more in height. No sandstone occurs in place here, though, at the summit, a few small fragments are found, together with much compact oolitic chert and quartzite.

At stations 85 and 86 bluffs of massive magnesian limestones like the last, rise to heights of 180 and 200 feet.

At station 87 figure 56 was measured.

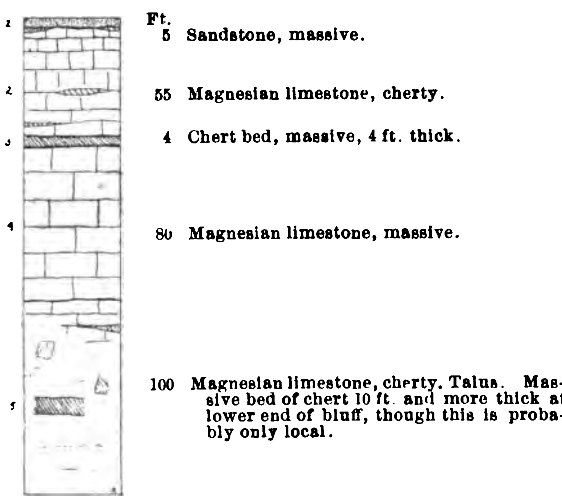
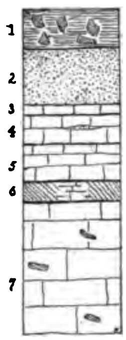


Fig. 56. Section at Station 87.

Here we find sandstone again coming in, but at a higher level than any before observed. It is, moreover, different lithologically, being more massive and containing fragments of chert; it is, further, not false-bedded to any great extent, nor is the contact with the underlying rock very irregular. This we name the Moreau sandstone.

At station 88, the hill is 130 feet high. The upper 10 feet are composed of massive layers of sandstone. This shows a considerable dip northward from the last exposure.

At Osage Bluff the section of figure 57 was obtained.



	Ft.	
1		Honeycombed quarzite or chert over surface; also masses of brecciated chert.
2	80	Sandstone, contact irregular beneath, but not unconformable; lower beds thin, with quartzite patches; upper part massive, in beds 8 inches thick; small grains of chert in sandstone.
3	4	Cotton rock
4	15	Magnesian limestone, with thin lenticular layers of sandstone and some chert.
5	20	" " thinner bedded, pitted weathering.
6	10	Brecciated chert and magnesian limestone.
7	70	Magnesian limestone in massive, rugged beds, with cavities; small amount of chert in rough masses, to river level

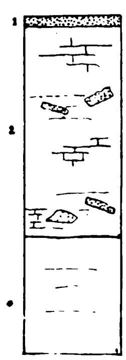
FIG 57. Section at Station 89.

Up the road leading from the ferry northward, this sandstone is well exposed, and above this, magnesian limestone crops out to a thickness of fully 80 ft. more.

At station 92, this heavy-bedded sandstone is exposed about 150 ft. above the river.

At Castle Rock (station 92 a), on the north side of the river, the top of the Moreau sandstone is about 200 ft. above the stream, and is apparently very thick, covering the surface profusely over an interval of 50 ft. below the top. Thence down the river, no further exposures were seen, and the sandstone is apparently above the tops of the adjacent bluffs.

At station 94, the last section was measured and is shown in fig. 58.



	Ft.	
1	5	Sandstone, white and fine grained.
2	110	Slope, with numerous outcrops of magnesian limestone and blocks of sandstone 1 ft. to 2 ft. in thickness
•	60	Slope, no outcrop.

FIG. 58. Section at Station 94.

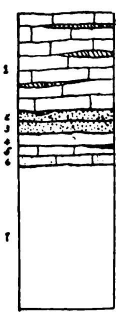
It is possible that the rock capping this section is the Moreau sandstone, but further work is needed to fully substantiate this.

Sections along the Moreau.—North of the Osage, between Osage Bluff and its mouth, the sandstone of the former place is abundantly exposed along the Moreau, and its distribution was specially studied. At station 101, it is exposed between 20 and 30 ft. above the creek level. It is here apparently only about 10 ft. thick.

Along the Wardsville and Jefferson City road, just north of the former place, exposures of the Moreau sandstone are abundant. At station 102, the rock is 120 ft. above the creek, while at station 103 it is only 50 ft., showing a strong northward dip. At the latter point, it is exposed in massive blocks 15 or more feet thick, somewhat false-bedded, and containing much chert in grains and also in small fragments. A layer of rough, gnarled chert seems to immediately cap the sandstone here.

At station 104, sandstone occupies an interval of 30 ft. as indicated. At station 105, it is only about 20 ft. thick. The base is here about 80 ft. above the creek, while immediately on the opposite side of the creek it is only 40 ft. above the water level, indicating a slight fault.

At station 106, figure 59 was measured.



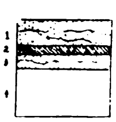
Ft.
30 Magnesian limestone, thinly bedded, with chert in layers and nodules, in strings and brecciated masses, with dolomite matrix.
8 Sandstone, less massive, rougher, chert grains and fragments near top.
4 Sandstone, massive, indurated, regular.
3 Slope.
3 Magnesian limestone, cherty, hard.
3 Magnesian limestone, sandy, cherty.
44 Slope, with large blocks of sandstone.

FIG. 59. Section at Station 106.

This section satisfactorily proves the thinning of this sandstone northwestward.

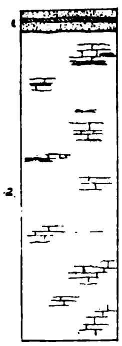
At points lower down the creek, this rock is exposed at different places, at elevations indicated on the map. At station 108, the sandstone is at water-level and only about 9 ft. thick. In the hill, about 150 ft. above this, thin layers of white, friable sandstone are intercalated with the magnesian limestone.

At stations 109 and 110 the sections of figures 60 and 60a were measured.



Ft.
8 Sandstone, roughly bedded, with wavy outlines.
3 Chert, gnarled, with sandstone and magnesian limestone in cavities and between the layers.
4 Sandstone, thinly and irregularly bedded.
30 Slope to water-level.

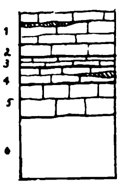
FIG. 60. Section at Station 109.



Ft.
10 Sandstone in two thin layers, with chert between.

180 Magnesian limestone, in almost continuous outcrops to water-level, upper half with chert, lower portion with massive cotton rock.

FIG 60a. Section at Station 110.

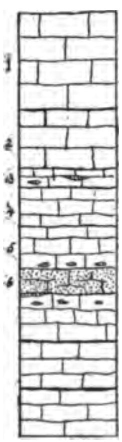


Ft.
Chert and magnesian limestone.
4 Sandstone, massive
8 Limestone, shaly and cherty.
5 Magnesian limestone, with chert.
10 Magnesian limestone, pitted, tough (quarried)
20 Slope to water-level.

FIG 61. Section at Station 111.

It is difficult to explain the presence of this sandstone of station 110 so high in the bluffs, unless it be caused by a fault. There certainly is no sandstone beneath, unless it be below the level of the creek.

Sections along the Missouri river. From the mouth of the Moreau to Gray's creek, above Jefferson City, a series of sections were measured, beginning with one at the mouth of the Moreau, illustrated in figure 62. They show in great detail the composition of what we have named the Jefferson City limestone.



Ft.

20 Cotton rock (magnesian limestone) pale blue, weathering to a brown color, layers 8 in. to 2 ft.; no chert.

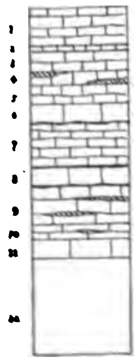
12 Magnesian limestone, massive beds, 2 to 5 ft. thick; granular and hard, some oolitic chert in nodules and lenticular layers, bluish-gray color, thinly bedded near base.
4 Magnesian limestone, less granular; much glassy nodular chert, some of which is angular and brecciated.
8 Magnesian limstone, massive, siliceous, granular, with a somewhat pitted weathering.
9 Magnesian limestone, more earthy and shaly, in part a cotton rock; fractured in checks; lower 2 ft. cherty in nodules and thin layers.
5 Sandstone (MOREAU), or very siliceous magnesian limestone; upper half with layers of quartzite parallel to stratification; also streaks of pure magnesian limestone; false bedded near bottom, and lower contact irregular; weathered surface highly siliceous; interior more like magnesian limestone
10 Magnesian limestone, massive, granular, upper 2 ft. contain much chert in nodular and thin layers; lower part irregularly bedded in places; elsewhere grading into rock below.
10 Magnesian limestone, massive, gray, pitted on fresh fracture; minute white patches, from decomposed chert; good building rock.
6 Limestone, rugged, with open cavities.

FIG. 62. Section at Station 112.

Nos. 6, 7 and 8 we feel no hesitancy in correlating with Nos. 2, 3, 4 and 5 of figure 61. It is plain that the sandstone bed has not only become noticeably thinner, but is also changing into limestone. The beds of this sandstone at the railway bridge are about 20 ft. above the water; thence it dips northward, so as to reach the river level within a distance of about 300 ft.

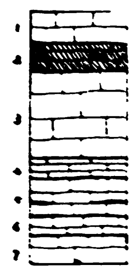
Proceeding westward along the railway from Moreau creek, the strata of the preceding section can be traced continuously. The bed numbered 3 is noticeably persistent.

About two miles from the creek, a series of higher lying beds, shown in figure 63, were measured.



Ft.
8 Magnesian limestone, shaly; thin and irregularly bedded, with chert and drab cotton rock.
1 Hard, siliceous looking bed, gray.
4 Cotton rock, thinly bedded.
8 Magnesian limestone, dark gray, irregularly bedded, with much dark chert.
4 Cotton rock, drab and buff
4 Magnesian limestone, gray, with streaks of cotton rock; lower 18 ins. hard and massive; irregular contact below.
9 Cotton rock, beds 6 ins. to 18 ins. thick (No. 1 of figure 62).
4 Magnesian limestone, more massive; gray; intermediate between No. 7 and No. 8.
8 Magnesian limestone, very massive, dark gray, some chert.
3 Magnesian limestone, cherty layers; massive (No. 3 of figure 62).
4 Magnesian limestone, massive.
20 Slope and railway fill to river.

FIG. 63. Section at Station 113.

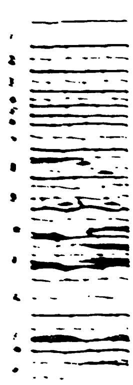


Ft.
3 Magnesian limestone, massive.
3 Cherty layer (No. 3 of figure 62).
9 Magnesian limestone, massive, dark gray.
2 Magnesian limestone, shaly, and cotton rock, weathering white.
4 Magnesian limestone, contorted, very irregularly bedded; dark gray; hard, with bands of dark chert.
2 Shaly white layer.
3 Magnesian limestone, gray; checked fracture, cherty near bottom.

FIG. 64. Section at Station 114

Nos. 4, 5, 6 and 7, of figure 64, are the same as No. 5 of figure 62.

Just east of the Jefferson City depot, the section of figure 65 was measured in detail.



Ft.
3 Loess
3 Cotton rock, thinly bedded, and gray magnesian limestone, with chert
4 Cotton rock, thicker-bedded [illegible] chert
3 Magnesian limestone, gray, rough, streaks of cotton rock, irregularly bedded.
2 Cotton rock, drab
2 Magnesian limestone, gray, with white chert in nodules and irregular streaks.
3 Magnesian limestone, shaly, yellowish, thinly bedded
[illegible] Magnesian limestone, thinly bedded, with dark chert in nodules and streaks
4 Magnesian limestone, gray, thicker bedded, with chert in thin streaks near base; [illegible] contact below
[illegible] Cotton rock, gray, with chert in masses near the base
[illegible] Magnesian limestone, gray, very cherty and [illegible]; irregular contact.
[illegible] Cotton rock, [illegible], weathering buff; no chert; [illegible] contact below
3 Magnesian limestone, massive, [illegible] chert near base
2 Magnesian limestone, thinly bedded, gray, [illegible] contact below
[illegible] Magnesian limestone, massive, [illegible] chert in upper part
Chert layer at track, No. [illegible] of fig. 62

FIG. 65. Section at Station [illegible]

Thus far along the river, the several beds were traced with great readiness. They lay nearly horizontal, or gently undulating, different beds dipping down and rising up above the track successively. No faults were exposed. The sandstone does not reappear, but at Jefferson City its horizon cannot be much over 20 ft. beneath the railway track.

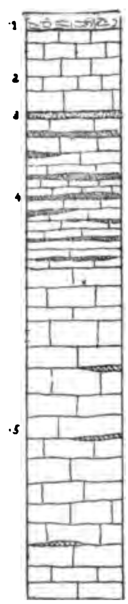


FIG. 66. Section of Jefferson City drill-hole.

On High street, in Jefferson City, about 150 feet above the railway, a well was drilled nearly 1200 feet. Figure 66 is constructed from the record.

The sandstone of this section is evidently that exposed at the mouth of the Moreau. Of the presence of lower-lying sandstone the drill-hole gave no indication.

West of the depot, the rocks assume a slightly westward dip, bringing the base of No. 12 of Fig. 65 down to within two feet of the track, at a point directly under the mansion. This dip continues westward, such that beds Nos. 10, 11 and 12 of that figure are entirely beneath the track-level at the capitol. Here figure 67 was measured.

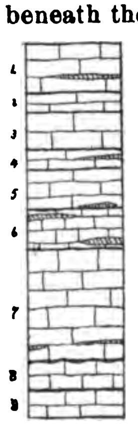
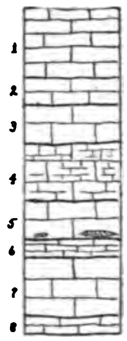


FIG. 67. Section at Station 116.

A half mile further west, figure 68 was measured.



Ft.

7 Magnesian limestone and cotton rock, with chert, like No. 7 of figure 67; thinly bedded; shaly contact beneath.

2 Magnesian limestone, cotton rock, more massive.

4 Magnesian limestone, rough, tough, pitted, like No. 9 of figure 67; irregular contact beneath.

6 Cotton rock, regularly bedded (3″ to 15″), very thin at base; irregular, hommocky contact below (No. 12 of figure 65).

4 Magnesian limestone, dense, tough, with chert near base.

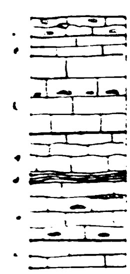
2 Cotton rock, thinly bedded, not separable always.

6 Magnesian limestone, derse, hard, rough.

2 Chert, nodular and brecciated, and magnesian limestone (No. 3 of figure 62).

Fig. 68. Section at Station 117.

At station 117, the thick beds of cotton rock have risen again to a height of about 12 ft. above the track, and the nodular and brecciated chert bed (No. 3 of station 112) is just at the track level. This stratum continues exposed almost to the pumping-house station, rising and falling with gentle undulations. It is very well marked, often containing cavities, the chert being very much brecciated and decomposed in places. At the quarry of the pumping-house station, the cotton rock beds (No. 4 of station 117) come down to the track level and descend below it, and the overlying beds are exposed continuously for a mile or more. Minor undulations characterize this stretch also.



Ft

2 Magnesian limestone with brecciated chert (No. 3 of figure 62).

8 Magnesian limestone, massive, dense; chert nodules about middle.

4 Magnesian limestone, more irregular and thinner bedded, dark gray; undulating below.

1 Shaly layer, ash gray.

6 Magnesian limestone, rough, shattered, seamy chert and nodules.

3 Magnesian limestone, dense, no trace of sandstone to track level.

Fig. 69. Section at Station 118

These conditions continue westward to the mouth of Gray's creek. The beds are nowhere continuously horizontal, but undulate gently all the way. At the last section measured, less than half a mile east of Gray's creek bridge, the beds of figure 69 were exposed.

No. 1 of this section we recognize as the breciated chert bed, No. 3 of station 112. It is fully 20 feet above the track, and we should, therefore, expect to find sandstone within the distance to the bottom; but no trace of it is shown. It is either absent here, or the interval between it and the chert bed has much increased.

Reviewing these sections along the Missouri river, they are interesting as an exhibit of the persistence of lithological characters of the different beds. The distance between the extreme exposures is about eight miles, and beds exposed at one end can be readily traced to the other. Further of interest is the fact that no faults worthy of notice are shown within this distance, but the rocks are traversed by a number of gentle undulations, with axes apparently running south of west.

High up, on the hills south of this line of sections, the overlying sandstone is found. Though widely distributed over the country, it is not in a continuous bed. It occupies depressions or hollows in the underlying limestones, and is found at different altitudes within very short distances. The following sketch illustrates its relations to adjacent rocks, as exhibited just south of Jefferson City:

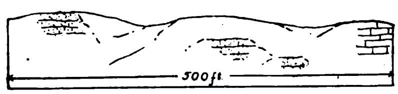


FIG. 70. Unconformity of limestone and sandstone near Jefferson City.

This rock is friable, sometimes white, sometimes of ferruginous color; it is very irregularly bedded. Stratigraphically, it belongs at the horizon of the Crystal City sandstone, and resembles it lithologically. The evident unconformity with the underlying magnesian limestone is in harmony with facts already described.

The sections of the Central district thus far given, throw much light upon the stratigraphy of the Silurian rocks. Additional work away from the larger streams is necessary in order to define the distribution of the different members.

The Cole Camp sandstone is well exposed south of Linn Creek, up the Niangua. At Gunter Spring it is to be seen in the bluffs, 130 ft. above the lake. It is there 10 to 12 ft. thick. A mile or so southwest of the spring, however, this sandstone seems to be brought to the bed of Spencer creek by a sharp flexure. The conditions here are illustrated in figure 71. It is possible that some faulting has taken place.

At other points, both north and south of the Osage river, sandstones are exposed. Their distribution can be readily mapped with a little detailed field-work over this area.

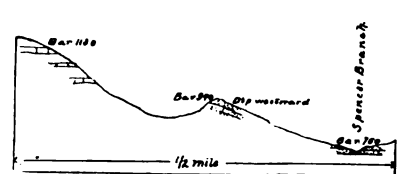


Fig. 71. Disturbance of strata, Gunter Sprs.

THE AGE OF THE OZARK STAGE.

The age of the rocks of the Ozark stage has been a question of more or less discussion, and still remains somewhat unsettled. Originally it was assigned by Swallow entirely to the Calciferous stage of the Lower Silurian series, though the Third sandstone, he thought, might be Potsdam, and the underlying Fourth magnesian limestone also. The discovery of a trilobite in the Third magnesian limestone by Meek, suggested the possible Potsdam age. This was later strengthened by the finding of the Lingulella at Mine La Motte, and of Lingula at other points. The question then became, were all of these rocks Cambrian, or only part of them? If the latter, what part, and where should the line be drawn on the map? Broadhead, following Swallow's suggestion, placed the line above the so-called Third sandstone [*32*, **p.** *358*]. Recently he has expressed the conclusion that the entire Ozark stage belongs in the Cambrian [*30*, **p.** *80*].

Work conducted by Mr. Frank L. Nason during 1892, over the Ozark area, led him to the conclusion that the so-called First, Second and Third sandstones do not exist as persistent beds, and are not of the stratigraphic value which the old classification gave them. He divides the series, so far as his observations went, into an overlying stratum, called Roubidoux sandstone (probably the equivalent of what we have called the Crystal City sandstone), and an underlying series of magnesian limestones, including some thin beds of sandstone, to which he applies the name of Gasconade limestone.

Stratigraphic work conducted by the writer, in southeastern Missouri, showed that the Lingulella beds of Mine La Motte belong higher in the series than has heretofore been thought [*248*, **p.** *221*]. These results are embodied in the section on p. 349 of this report. This, together with the fact of the Cambrian aspect of the Mine La Motte fossils, led the writer to express the opinion [*155*, **p.** *17*] that all of the Ozark rocks are of Cambrian age. Since that time, additional studies of fossils have been made and additional stratigraphic work has been done—sufficient to add much of value, and to considerably modify the views before expressed. The question is not yet entirely settled, but enough seems to have been proven to warrant the application of the name Lower Silurian to these rocks, even though it involves the admission of having expressed one's self too precipitately before.

The questions now to be considered are:

1. Is there any Cambrian in Missouri?
2. If so, how and where are the dividing lines to be drawn between it and other formations?
3. If so, again, what is the age of the overlying rocks?
4. If there be no Cambrian, to what age do all the rocks of the Ozark stage belong?

The first question can only be settled through a study of the fossils. In the next pages we give a table of all the fossils found in the Ozark rocks in Missouri, and their localities.

Of the species examined by Mr. Walcott, he says, in a letter to the writer: "All of these species indicate the Lower Ordovician or Calciferous fauna of the New York section. The Lingula-like shell is closely allied to *Lingulepis accuminata* Conrad, of the Upper Potsdam and Lower Calciferous, of the New York section. It may be identical with the *L. lamborni* Meek. The range of this type, so far as known to me, in our American rocks, is confined to the Upper Cambrian and Lower portions of the Ordovician." Again, he writes: "The 'Lingula' from Mine LaMotte is a form that is not positively a Cambrian type; on the contrary, it is probable that it ranges well up into the lower portion of the Ordovician."

Other specimens of these Lingulellas were examined by other authorities, who have kindly furnished the writer with the results of their examinations. Thus, Dr. John M. Clarke writes: "The linguloid brachiopods from the soft, greenish, argillaceous shales at Mine LaMotte are excellent representations of the genus Lingulella. The characteristic features of this genus are more than usually well developed in the specimens submitted to me—the triangular cardinal or subapical surface of the pedicle valve, with the narrow median pedicle-slit, being very conspicuous, while the muscular scars of both valves are clearly defined, and will materially add to our knowledge of the muscular structure in this genus. Another noteworthy character is the strongly pitted internal surface of both valves in the umbonal and median regions, a structural feature which it possesses in common with *L. davisi*, the type species; but I am not aware that it has been recorded of any other Lingulellas of this type: that is to say, the typical Lingulella is, so far as our present knowledge extends, restricted to Cambrian faunas. In specific features, I would compare the Mine LaMotte specimens directly with *L. davisi*—from the Lingula, flags of Wales,

TABLE OF FOSSILS FOUND IN THE

	Fossils.	Identified by	County.	Horizon.
1	Arionellus (?) missouriensis	Shumard	Ozark	2d mgls
2	" "	"	Wright	"
3	"	"	Ozark	3d mgls
4	Barythurus	Potter	Lincoln	1st mgls.
5	Chemnitzia vesticula	Shumard	Ozark	2d mgls
6	" ozarkensis	"	"	"
7	"	"	"	3d mgls
8	"	"	Wright	2d mgls
9	"	"	Laclede	"
10	"	"	Ozark	Sacc ss
11	Cytocecras, like Nos. 12 and 13	Walcott	Pulaski	Ozark stage
12	" sp. undet.	"	Maries	"
13	" "	"	Washington	"
14	Cyotolites, sp ?	Rowley	St. Louis	
15	Cythere sublævis	Shumard	"	1st mgls.
16	" "	"	Ste. Genevieve	"
17	Euomphalus	Meek	Miller	2d mgls.
18	"	"	"	3d mgls.
19	"	"	Morgan	2d mgls.
20	"	"	"	3d mgls.
21	" polygrata	"	"	"
22	"	"	Moniteau	"
23	"	Broadhead	Madison?	2d ss
24	Helicotoma ? (sp. A), same as Nos. 25 & 27	Walcott	Shannon	Ozark stage
25	" "	"	Christian	"
26	" "	"	Polk	"
27	" "	"	Christian	"
28	Helicotoma ? (sp. A)	Walcott	Shannon	Ozark stage
29	" "	"	Taney	"
30	" "	"	Webster	"
31	Holopea sp ?	Rowley		
32	" cf. obesa (Whitf.)	Walcott	Pulaski	Ozark stage
33	" " "	"	Washington	"
34	Leptæna	Swallow	Central Mo	2d ss
34a	"	Rowley	"	"
35	Lingulella lamborni (M)	Broadhead	Madison	Mgls series
36	Lingula	"	Cole	2d mgls
37	"	Shumard	Jefferson	3d mgls
38	"	"	"	"
39	" (A); similar to L. prima.	Walcott	Polk	Ozark stage
40	" prob the same (Lacuminata?); see note to No. 41	Walcott	Polk	"
41	" lamborni (Meek) resembles No 40; difference may be due to sediments	Walcott	Madison	"
42	Lingulella lamborni (Meek)	Beecher	"	"
43	" like L. davisii (Sutter); also lik· L. ella (H. & W.)	Ulrich	"	"
44	" like L. davisii; like L. stoneana (Whitf.); like L. ella (H. & W.)	J. M. Clarke	"	"
45	Lituites complanata (Sh.)	Shumard	Ozark	2d mgls
46	Lonchocephalus sp ?	Meek	Morgan	3d mgls
47	Melia primogenium	Shumard	Ozark	2d mgls
48	Murchisonia	"	Jefferson	"
49	" ozarkensis	Broadhead	Cole	2d ss
50	" carinifera	"	"	"
51	" "	Shumard	Laclede	3d mgls
52	" "	"	Cape Girardeau	"
53	" melaniaformis	"	Franklin	2d mgls
54	" "	Rowley	"	"
55	"	Meek	Moniteau	"
56	"	"	"	2d ss
57	"	Shumard	Franklin	2d mgls
58	" melaniaformis	"	Ozark	"
59	" carinifera	"	"	"
60	" melaniaformis	"	"	"
61	" "	Swallow	Cole	"
62	"	Meek		"
63	" near melaniaformis, but dist'ct	Walcott	Shannon	Ozark stage
64	" Sp. ?, round whorl	"	"	" "
65	" Sp. ?, angular whorl	"	"	" "

ROCKS OF THE OZARK STAGE.

Catalogue No.	Reference.	Remarks.
	Rept. 1855-71, p. 193	
	" p 209	
	" p 197	
	Rept 1872 pt II, p 230	
	Rept 1855-71, p 193	
	" "	
	" p 197	
	" p 209	
	" p 216	
	" p. 292	
3862	Mo. Geol Sur	F. L. Nason, col., Simpson's mill
3918	" "	" " "
5132	" "	J. D. Robertson, col., Poverty Flats
	Vol II, 1892, p. 111	
	Rept 1854, pt. II p 195	
	" " p. 174	Description and plate.
	Rept. 1855 71, p 123	
	" p. 124	
	" p 145	
	" p 147	Allied to *E. levata* or *E. complanata*
	" "	
	Rept 1854, p 108.	
	Rept 1873, p 364.	
3882	Mo. Geol Sur	F. L Nason, col., Township 31 N. 5 W
5029	" "	A. Winslow, col., at Armstrong mine
4083	" "	J. D. Robertson, col, Bolivar, Polk county.
5064 5065	" "	A. Winslow, col, Swan creek. Baker's creek
4536	Mo. Geol. Sur	R. R Rowley, col, Riverside, T 31 N. 6 W
2901	" "	J. D. Robertson, col., T 23 N 20 W
4082	" "	" " Teague's
	Vol. II, p. 110, 1892	
3862	Mo Geol. Sur	F. L. Nason, col., Simmons' mill
5132	" "	J. D. Robertson, col., Poverty Flats
	Rept 1854, I, p. 126	
	Vol. II. p 110. 1892.	
	Rept 1873, p 135.	
	" p 327	
	Rept. 1855-71, p 309	
	" p. 147	
4690	Mo. Geol. Sur	R. R. Rowley, col., Bolivar
5133	" "	J. D. Robertson, col., Bolivar
	" "	E. Haworth, col., Mine La Motte
	" "	" " "
	" "	E. Haworth, col., Mine La Motte
	" "	E Haworth, col., Mine La Motte
	Rept. 1855-71, p 193	
	" p 147	
	" p 193	*Orthoceras primogenium*
	" p 307	
	" p 327	
	Rept. 1873, p. 327	
	Rept. 1855-71, p 48.	
	" p 269	
	Rept 1854, I p. 124, II, pp. 164 and 208	Description and plate
	Vol II, p 110, 1892	
	Rept 1854, II, p 108	
	" I, p 120	
	" I, p. 164	
	Rept 1855-71, p. 193.	
	" "	
	Rept 1854, I, p 124	
	" I. p 124	
	" I, p. 123	
3860	Mo. Geol. Sur	F. L. Nason, col., Twp. 25 N, 4 W
38-2	" "	" " 31 N., 5 W
3882	" "	" " "

TABLE OF FOSSILS FOUND IN THE

	Fossils.	Identified by	County.	Horizon.
66	Murchisonia melaniaformis (Shum.) See No. 66	Walcott	Christian	Ozark stage
67	" probably distinct from last	"	Polk	" "
68	" melaniaformis (Sh.)	"	Christian	" "
69	Nautilus cf. kelloggi (Whitf.)	"	St. Francois ?	" "
70	Orthis antiqua	Broadhead	Cole	2d ss
70	"	Rowley		
72	"	Shumard	Ozark	3d mgls
73	"	Swallow	"	"
74	"	"	"	2d ss
75	Orthis electra (Billings)	Walcott	Shannon	Ozark stage
76	Orthoceras primogenium	Shumard	Ozark	2d mgls
77	" "	Rowley		
78	"	Broadhead	Madison	Below mg. ser.
79	"	Shumard	Cape Girardeau	3d mgls
80	" primogenium	"	Franklin	2d mgls
81	"	"	"	2d ss
82	"	Broadhead	Maries	Sacc. ss.
83	" ?	"	Warren	"
84	"	Shumard	"	1st mgls
85	"	"	"	2d ss
86	Ophileta (see Straparollus)			
87	"	Potter	Lincoln	1st mgls
88	" complanata	Rowley		
89	" levata	Meek	Moniteau	?
90	Pleurotomoria	Broadhead	Cedar	Mgls. series
91	" turgida	Hall	Cole	2d ss
92	"	Shumard	Pulaski	3d mgls
93	"	Rowley		
94	"	Shumard	Franklin	3d mgls
95	"	"		"
96	"	"	Franklin	2d mgls
97	"	"	"	2d ss
98	"	Meek	Miller	3d mgls
99	"	"	Morgan	2d mgls
100	"	"	"	3d mgls
101	"	"		2d mgls
102	"	Shumard		2d ss
103	Pleurotomaria ? (sp. A)	Walcott	Christian	Ozark stage
104	" cf. canadensis (Bill.)	"	Pulaski	"
105	" " "	"	Washington	"
106	" " "	"	"	"
107	" may be the same	"	Shannon	"
108	" cf. canadensis (Bill.)	"		"
109	" " "	"	"	"
110	Raphistoma subplana	Broadhead	Cole	2d ss
111	" sp. ?	Rowley		
112	"	Shumard	Ozark	2d ss
113	" grandis (S)	"	"	2d mgls
114	" subplana (S)	"	"	"
115	"	Walcott	Shannon	Ozark stage
116	" prob. sp. A. same as Nos. 117 and 118	"	"	"
117	"	"	Washington	"
118	" sp. A	"	Franklin	"
119	Straparollus	Shumard	Jefferson	2d mgls
120	" reticulata	"	Cedar	"
121	" minnesotensis	Rowley		
122	"	Shumard	Cedar	2d mgls
123	" reticulata	Broadhead	Cole	2d ss
124	" acutocarinatus	Shumard	Ozark	"
125	" "	"	"	3d mgls
126	" bigranosus	"	"	2d mgls
127	"	"	"	"
128	"	"	Laclede	"
129	" acutocarinatus	"	"	3d mgls
130	"	"	Pulaski	"
131	"	"	Cape Girardeau	3d mgls
132	" complanata	"	Franklin	"
133	" levata	"	"	"
134	"	"	"	2d mgls
135	"	"	"	2d ss
136	"	"	Ozark	Sacc. ss
137	" valvatiformis	"	"	2d mgls
138	" bigranosis	"	"	"

ROCKS OF THE OZARK STAGE—Continued.

Catalogue No.	Reference.	Remarks.
5029	Mo. Geol. Sur	A. Winslow, col., Armstrong mine 66
4083	" "	J. D Robertson, col., Bolivar
5064	" "	A. Winslow, col., Swan creek
5134	" "	J. D. Robertson, col., Doe Run (?)
	Rept. 1873, p 327	70
	Vol. II. p 110, 1892	
	Rept. 1855-71, p 197	
	Rept. 1854, I, p. 127	
	" p. 126	
3855	Mo. Geol Sur	F. L. Nason, col., Twp. 31, N. 6 W
	Rept 1855-71, p 193	
	Vol. II p 110, 1892	
	Rept. 1873, p 357	
	Rept. 1855-71, p 269	
	Rept. 1854, II, p 168	80
	" " p 167	
	Rept. 1855-71, p. 10	
	" " " p 55	
	Rept. 1854, I, p. 116	
	" " " p. 126	
	Rept. 1872, I, p 230	
	Vol. II, p 110, 1892	
	Rept. 1854, II, p. 108	
	Rept. 1873, p 65	90
	" " p 327	
	Rept 1855-71, p. 269	
	Vol II, p 110, 1892	
	Rept. 1854, II, p 168	
	" " I, p 127	
	" " II, p 164	
	" " II, p. 167	
	Rept. 1855-71, p. 124	
	" " " p 145	
	" " " p. 147	100
	Rept. 1854, I, p. 123	
	" " I, p. 126	
5029	Mo Geol. Sur	A. Winslow, col., Armstrong mine
3862	" "	F. L. Nason, col., Simmons' mill
5132	" "	J. D Robertson, col., Poverty Flat
5131	" "	" " Twp. 37, N. 1 W
4596	" "	R. R. Rowley, col, Akers P O., Twp. 31 N. 6 W
4087		
4536	Mo. Geol. Sur	R. R. Rowley, col., Riverside, Twp 31, N., 6 W
	Rept. 1873, p 327	110
	Vol. II, p 110, 1892	
	Rept. 1855-71, p 195	
	" " p. 193	
	" " p. 193	
3860	Mo. Geol. Sur	F. L. Nason, col., Twp. 25 N., 4 W
3882	" "	" " Twp. 31 N., 5 W
5182	" "	J. D. Robertson, col., Poverty Flats
5180	" "	" " Twp. 42 N., 1 W
	Rept. 1855-71, p 309	
	Rept. 1873, p. 65	120
	Vol. II, p. 110, 1892	
	Rept. 1873, p. 65	
	" 1873, p 327	
	" 1855-71, p. 195	
	" " p. 197	
	" " p. 209	
	" " p. 209	
	" " p. 216	
	" " p. 218	
	" " p. 228	130
	" " p. 269	
	Rept. 1854, I, p. 127, II, 168	or Ophileta
	" " " "	"
	" " II, p 164	
	" " I, p 167	
	" 1855-71, p. 193	
	" "	
	" "	138

TABLE OF FOSSILS FOUND IN THE

	Fossils	Identified by	County.	Horizon.
139	Straparollus levata (?)	Shumard	Benton	1st mgls
140	"	Meek	?	2d mgls
141	"	Shumard	?	"
142	"	Swallow	Benton	"
143	"	"	?	"
144	" sp. ?	Walcott	Washington	Ozark stage
145	Turbo	Meek	Miller.	3d mgls
146	"	Shumard	Franklin	"
147	Trilobite	"	Ozark	2d mgls
148	"	Swallow		2d ss
149	Tryblidium ovatum (Whitf. ?)	Walcott	Washington	Ozark stage
150	" " "	"	"	"
151	Zaphrentis ?	Broadhead	Madison	Below mg. ser.

though the latter is of larger size, and somewhat more quadratic outline; with the *L. Stoneana*, Whitfield, from the Potsdam horizon, at Mazomanie, Wisconsin; and with *L. ella*, Hall and Whitfield. Of all these, perhaps the closest agreement in the outline of the valves is with *L. ella*."

Prof. Charles H. Beecher, of Yale museum, writes that the expression of the species examined indicates a Cambrian age of the rocks.

Prof. E. O. Ulrich, in a private communication, identifies the specimen as belonging to the genus Lingulella, and states that "all true species of Lingulella now known are Cambrian, so that the mere presence of any one of them in strata of which we know nothing to the contrary, may, of itself, be regarded as good evidence, not necessarily conclusive, however, that they are of Cambrian age." He adds that the Missouri species is different from the know American forms, and this adds a degree of uncertainty to the determination of the age of the rocks holding them.

All these authorities unite upon the desirability of confirming the evidence of these shells by other associated fossils. The feeling is, therefore, that these shells in themselves do not fix the age of the rock, and that their significance is dependent upon the associated forms, and upon the stratigraphic relations of the beds enclosing them to the surrounding formations.

Now, a study of the preceding descriptions and sections of southeastern Missouri shows that these Lingulella beds are not demonstrable at the base of the sections. It is true they rest on, or are near the Archean rocks; but this is because of the unconformity of the contact. Any part of a later formation may thus be in contact with the Archean. The stratified rocks here do not encircle the Archean

ROCKS OF THE OZARK STAGE—Continued.

Catalogue No	Reference.	Remarks.
	Rept. 1854, pt. I, p. [illegible]	[illegible]
	" 1854, pt. I, p. [illegible]	
	" 1854, pt. I, p. [illegible]	
	" 1854, pt. I, p. [illegible]	
	" 1854, pt. I, p. [illegible]	
[illegible]	Mo. Geol. Sur	J. D. Robertson, col., Poverty Flats
	Rept. 1854-71, p. [illegible]	
	" 1854, I, p. [illegible]	
	" 1854-71, p. [illegible]	
	" 1854, II, p. [illegible]	
[illegible]	Mo. Geol. Sur	J. D. Robertson, col., Poverty Flats
[illegible]	" "	" " Twp. [illegible] N. 1 W.
	Rept. 1873, p. [illegible]	[illegible]

nucleus in regular and uniform order, as do the rocks of the Black hills of Dakota. On the contrary, they were laid down on an old eroded surface, where they have filled depressions between mountains. Consequently, the oldest deposits do not come to view on the sides of the Archean hills, but occupy the depths of the basins. From the sections, it is plain that the Mine LaMotte limestone belongs to the great body of limestone of the southeast, in which other fossils of Lower Silurian or Ordovician aspect have been found. We correlate this limestone with what we call the St. Joseph limestone in the table on p. 331. Shumard further refers to the finding of "lingula" shells [*33, p. 309*] at higher horizons. Though we have not seen these specimens, nor had them examined, we think it probable that the species is the same as that found at Mine LaMotte.

In conclusion, therefore, though there is still call for further work, especially in the search for closely associated fossils and in the study of the stratigraphy, we think the signs point plainly to the conclusion that these rocks of the Ozark stage belong to the early Silurian or Ordovician age. If Cambrian rocks exist at the base, there is certainly no stratigraphic break, and the separation must be a purely paleontologic one.

THE DEVONIAN.

The Devonian in Missouri is very poorly represented, and is almost absent in southern Missouri. Either the rocks of this system were never deposited here, or they have been almost entirely eroded. In either case, their absence proves a long erosion period and consequent unconformity. In the Central district there are no rocks of this period. In the Southeastern, Dr. Shumard identifies certain thin beds of gray